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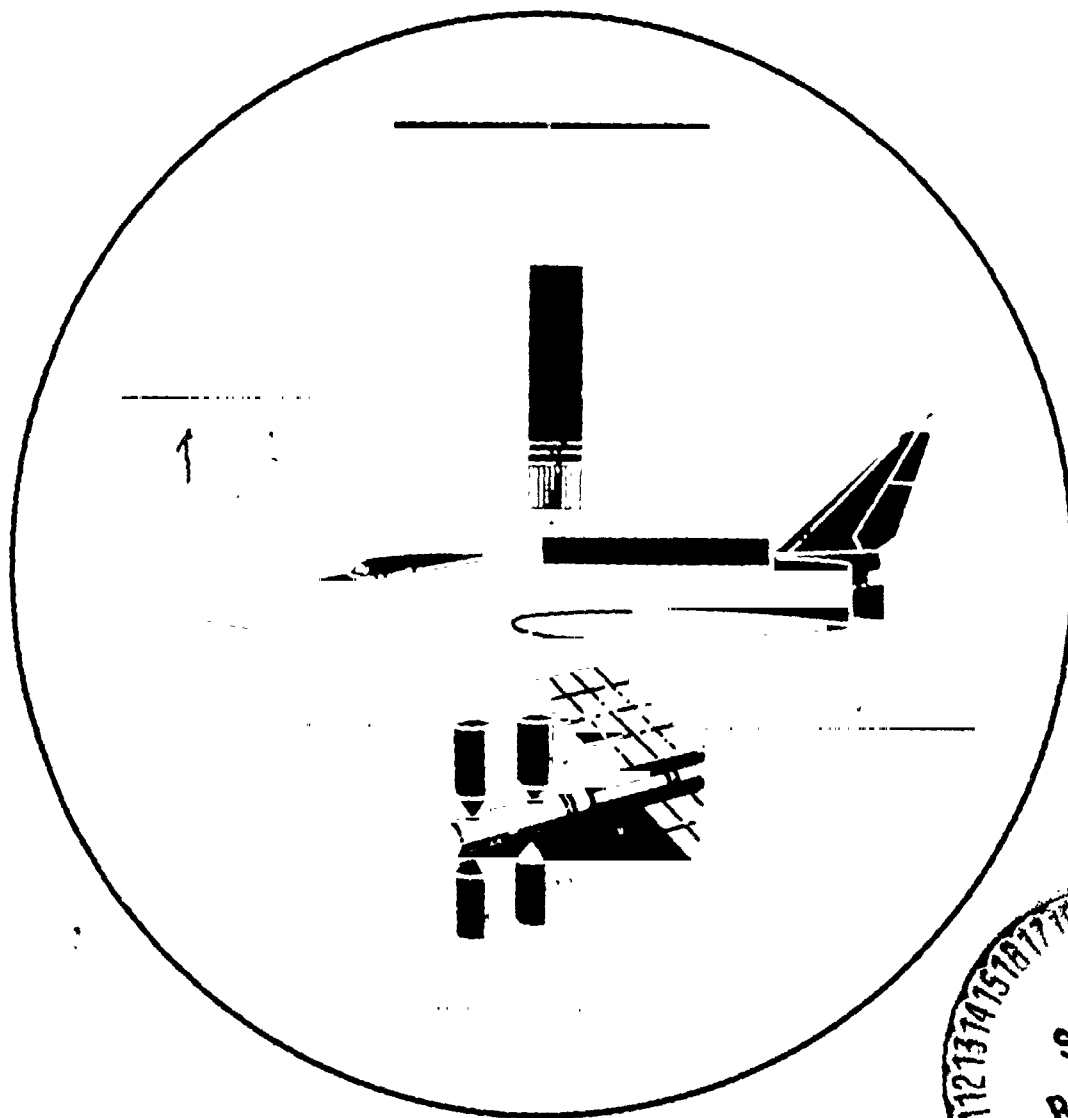
**FINAL REPORT**

*CR-128508*

# Safety in Earth Orbit Study

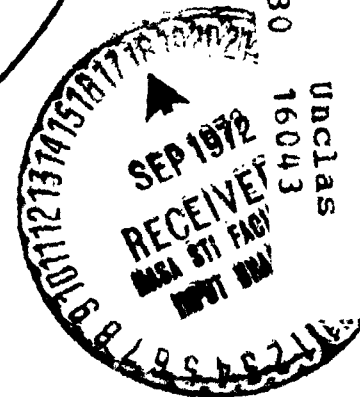
## Volume II – Analysis of:

- Hazardous Payloads
- Docking
- On-Board Survivability



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Space Division  
North American Rockwell

MSC-04477  
SD 72-SA-0094-2

**FINAL REPORT**  
**Volume II**  
**Analysis of:**

● Hazardous Payloads   ● Docking   ● On-Board Survivability

# **Safety in Earth Orbit Study**

JULY 12, 1972  
Contract NAS9-12004

Approved by



G. S. Canetti  
Study Manager



**Space Division**  
North American Rockwell

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# FOREWORD

Final documentation of the Safety in Earth Orbit Study is submitted by the Space Division of North American Rockwell Corporation to the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, in compliance with DRL Line Items 3 and 4 of NASA-MSC Contract NAS9-12004.

The 12-month study was performed for the NASA Manned Spacecraft Center by the Space Applications Programs organization at the Space Division of North American Rockwell. Mr. P. E. Westerfield of the Safety Office was the NASA technical manager.

Documentation of the study results is as shown in the following table.

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3	Final Report	
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	Volume III - Analysis of: Tumbling Spacecraft Escape and Rescue	SD 72-SA-0094-3
	Volume IV - Space Shuttle Orbiter Safety Requirements and Guidelines On-Orbit Phase	SD 72-SA-0094-4
	Volume V - Space Shuttle Payloads Safety Requirements and Guidelines On-Orbit Phase	SD 72-SA-0094-5



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Personnel at North American Rockwell who participated in the study are:

All tasks	-	R. E. Altenbach
Hazardous Payloads	-	L. K. Relyea
Docking	-	G. O. Mount, Jr.
On-board Survivability	-	B. L. Felmet J. W. Patrick
Tumbling Spacecraft	-	A. Cormack III A. N. Moore B. U. Mahr
Escape and Rescue	-	C. N. Harshbarger B. U. Mahr



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## 1.0 INTRODUCTION

Most of the manned spaceflight programs planned by NASA for the late 1970's and 1980's are concentrated on earth orbital operations. These will use the shuttle and a variety of manned and unmanned payloads delivered to orbit by the shuttle.

The Safety in Earth Orbit Study examined five specific safety issues associated with these operations. The study logic used is shown in Figure 1-1. The five issues were studied as five separate tasks and these were performed in the order shown.

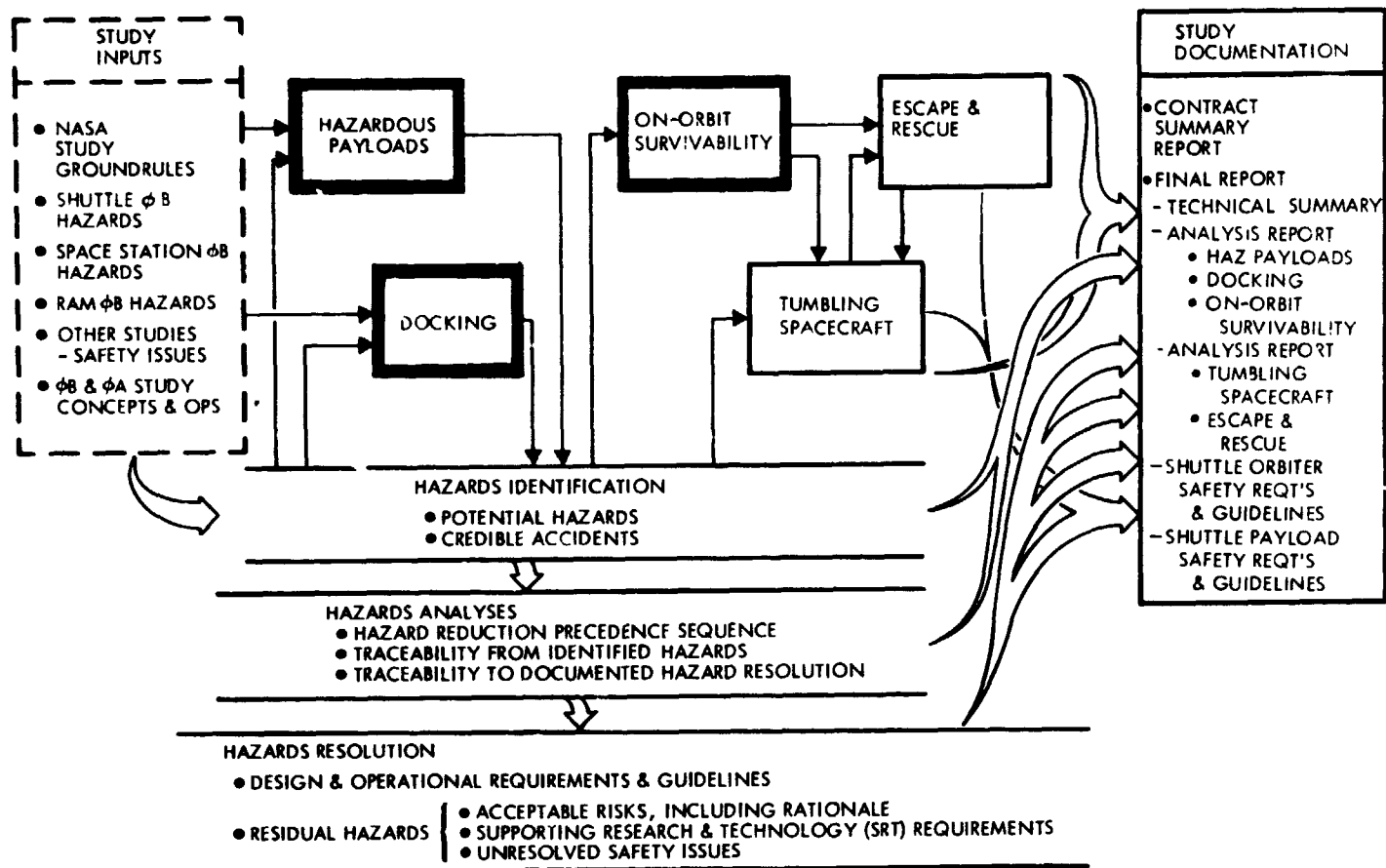


Figure 1-1. Study Logic



This volume presents the technical analysis for the first three tasks, which are shown by the heavy outline in the study logic. These three tasks used hazard/emergency analyses as a prime technique for generating safety requirements and guidelines. These latter form an important part of the study output, and are documented separately in Volumes IV and V of this report.

## 1.1 SCOPE

The study scope covered the vehicles shown in Figure 1-2.

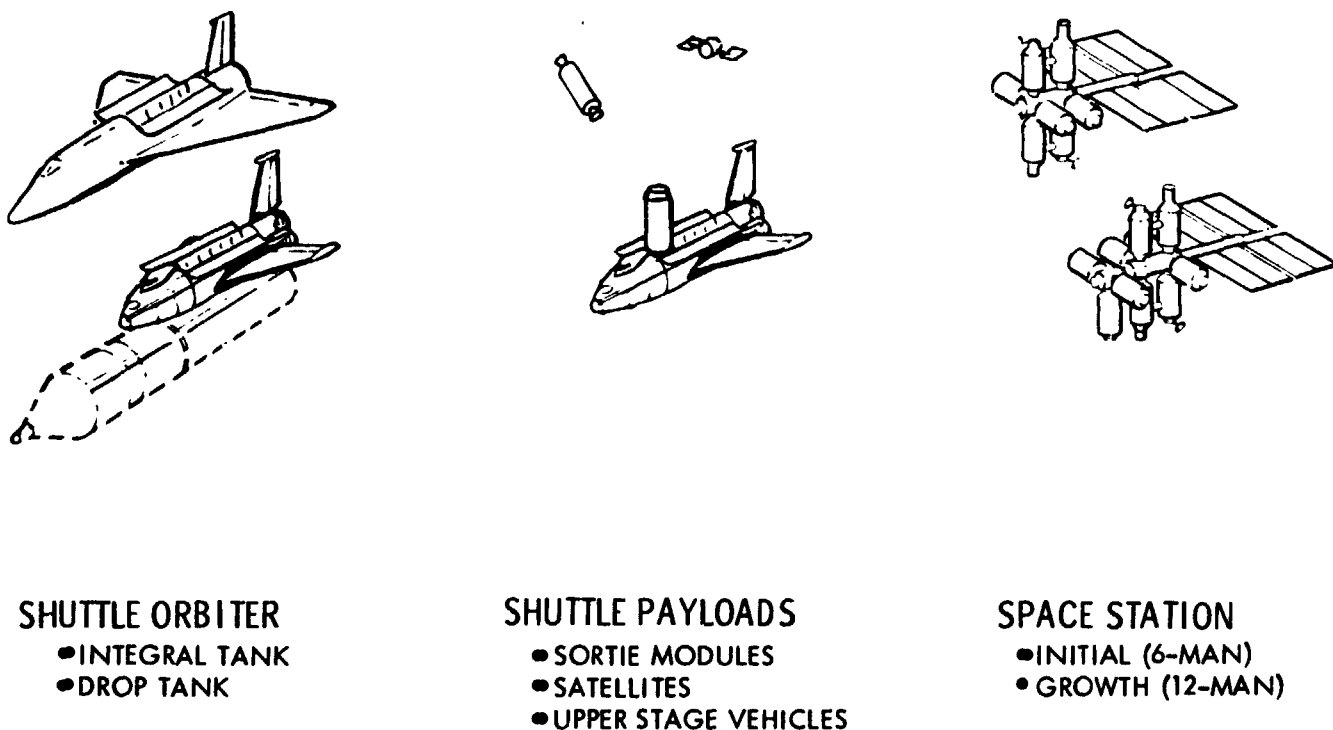


Figure 1-2. Vehicles Considered in Study

Initial tasks were based on the integral tank shuttle orbiter, but emphasis was later switched to the drop tank orbiter as this concept developed. The assumptions made were broad enough that no results were invalidated by this change.

Shuttle payloads considered included manned and unmanned sortie payloads (i.e., attached to the orbiter), satellites delivered to earth orbit, and potential upper stage vehicles, such as the tug, Agena, Centaur, etc., used to deliver unmanned payloads to orbits beyond the orbiter's capabilities.

The space stations considered were modular stations delivered to earth orbit and assembled by the orbiter. Initial 6-man versions and growth versions with up to 12 men, as defined in recent Phase B studies, were studied.



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To the maximum extent possible, the analyses were performed with the minimum configuration oriented and operational assumptions possible, in order to have the results applicable over as wide a range of changes from currently planned programs as possible.

Within the scope of the vehicles described, the study is bounded by the following study ground rules:

- The main concern is personnel safety. A lesser emphasis was placed on avoiding damage to or loss of the vehicles.
- The analysis was confined to the manned on-orbit phase of missions. Launch, boost, deorbit, reentry and landing of the orbiter, or unmanned operations of the station and upper stage vehicles away from the orbiter were not considered.
- The study results cover only the specific concerns of the study. They must not be assumed to cover all safety aspects of the relevant vehicles.

## 1.2 STUDY OBJECTIVES

The study concerned itself with five specific issues. These issues and their objectives are:

1. Hazardous payloads. The objective was to identify hazards associated with certain orbiter payloads and to determine safety requirements and guidelines.
2. Docking. The objective was to compare a number of different approaches for docking an orbiter to a space station, and to recommend the methods preferred from a safety point of view.
3. On-board survivability. The objective was to determine the configurational and other requirements for the orbiter, sortie module and space station to allow personnel to survive on-board emergencies.
4. Tumbling spacecraft. The purpose was to determine practical means for arresting the motion of out-of-control tumbling spacecraft by external means, or to allow on-board personnel to escape from a spacecraft if tumbling cannot be arrested.
5. Escape and rescue. The objective was to determine the applicability of previous or new concepts for escape, rescue and bail-out survivability to the orbiter, sortie modules and space station.

This volume presents the technical analyses for the first three tasks. The last two tasks are reported in Volume III of this report.

### 1.3 RELATIONSHIP TO OTHER STUDIES

The Safety in Earth Orbit Study was performed in the context of a wide range of related studies. This relationship is shown in Figure 1-3.

The most important of these studies are the Phase B studies on the space station, shuttle and RAM (Research and Applications Modules). These studies were the main sources of data on the station, shuttle and sortie module, respectively. Phase A studies on the Tug, Orbit-to-Orbit Shuttle (OOS) and the Chemical Interorbital Shuttle, and systems studies on the Orbital Operations and the In-Space Propellant Logistics Studies provided additional information, both on relevant hardware elements and on operational modes.

A good interchange of information was possible with all these studies for which NR was a prime contractor (subcontractor on the RAM). The interchange of information and ideas generally flowed in both directions. This interchange was particularly fruitful with the Orbital Operations Study and the safety portion (Phase 2) of the ISPLS study.

Additional safety background was obtained from earlier safety studies by Boeing (on the space station), Lockheed (on the shuttle), and from ongoing studies by the Aerospace Corporation (on the shuttle and on escape and rescue). A particularly useful cooperative effort was also established with the Pennsylvania State University on the dynamics of tumbling spacecraft.

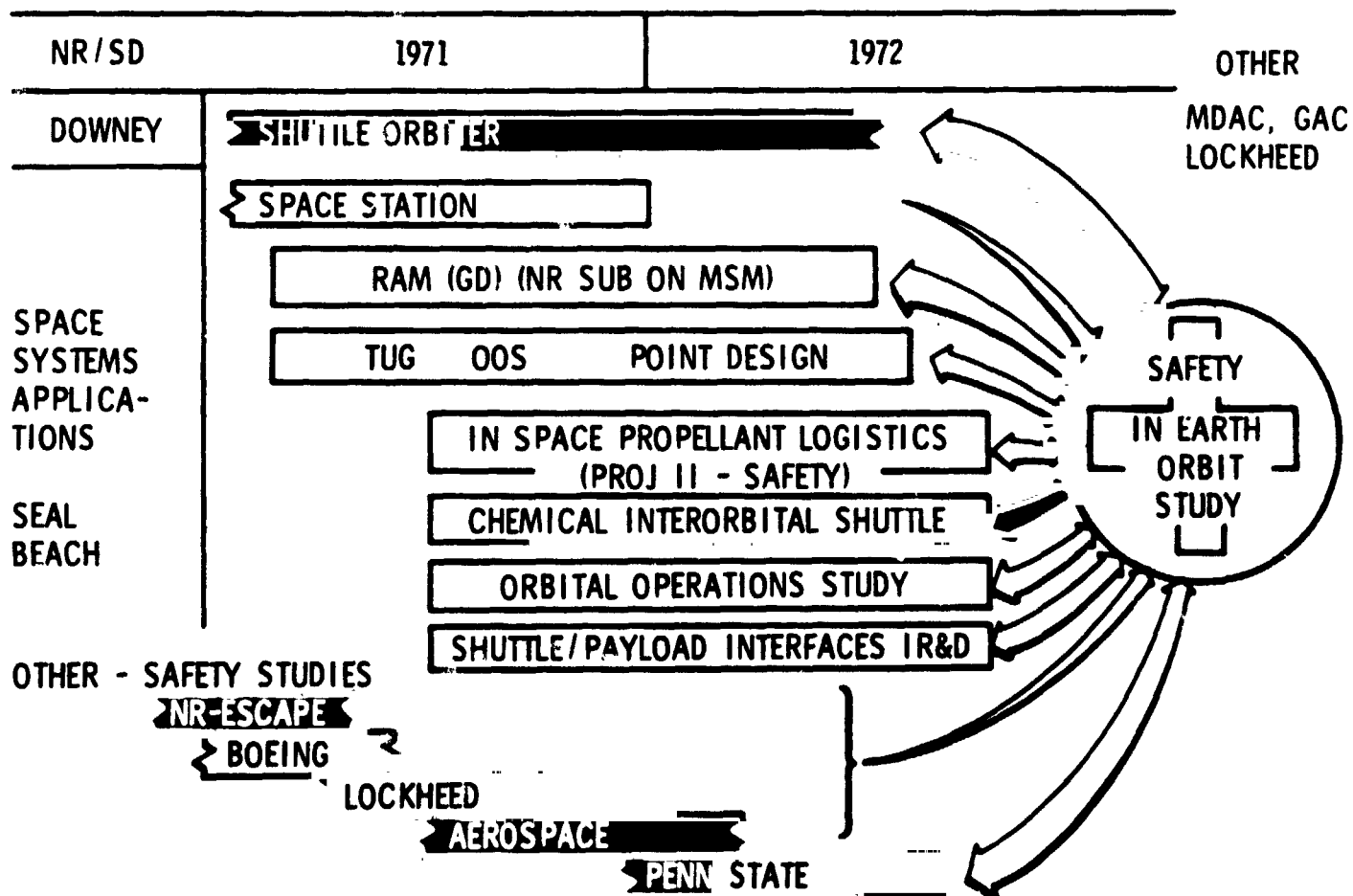


Figure 1-3. Relationship to Other Studies

#### 1.4 BASELINE MODEL

The baseline model discussed in this section describes typical shuttle orbiter configurations, shuttle missions, and the interfaces with the shuttle payloads, sortie modules, and the space station.

While this model is typical, many variations have been or are being considered. The attempt has been made to make the results of the entire study as insensitive to the concepts, configurations, operational modes, design details, and program schedules as possible, so as not to invalidate the study as the space program evolves. This has been done by dealing with the problems parametrically, and not typing the analyses to specific designs, sizes, or missions. The description of the baseline model that follows, therefore, should be read as describing typical current concepts, and not the concepts assumed for the study.

##### 1.4.1 Typical Shuttle Mission

A typical shuttle mission, shown in Figure 1-4, was generated from NR Phase B shuttle data to identify approximate projections of shuttle functions and timelines, and to illustrate the scope of this study within the shuttle mission. Earth orbit is interpreted for purposes of the study as encompassing that portion of the mission that starts with orbit injection and terminates with deorbit. On-orbit time can be up to 30 days.

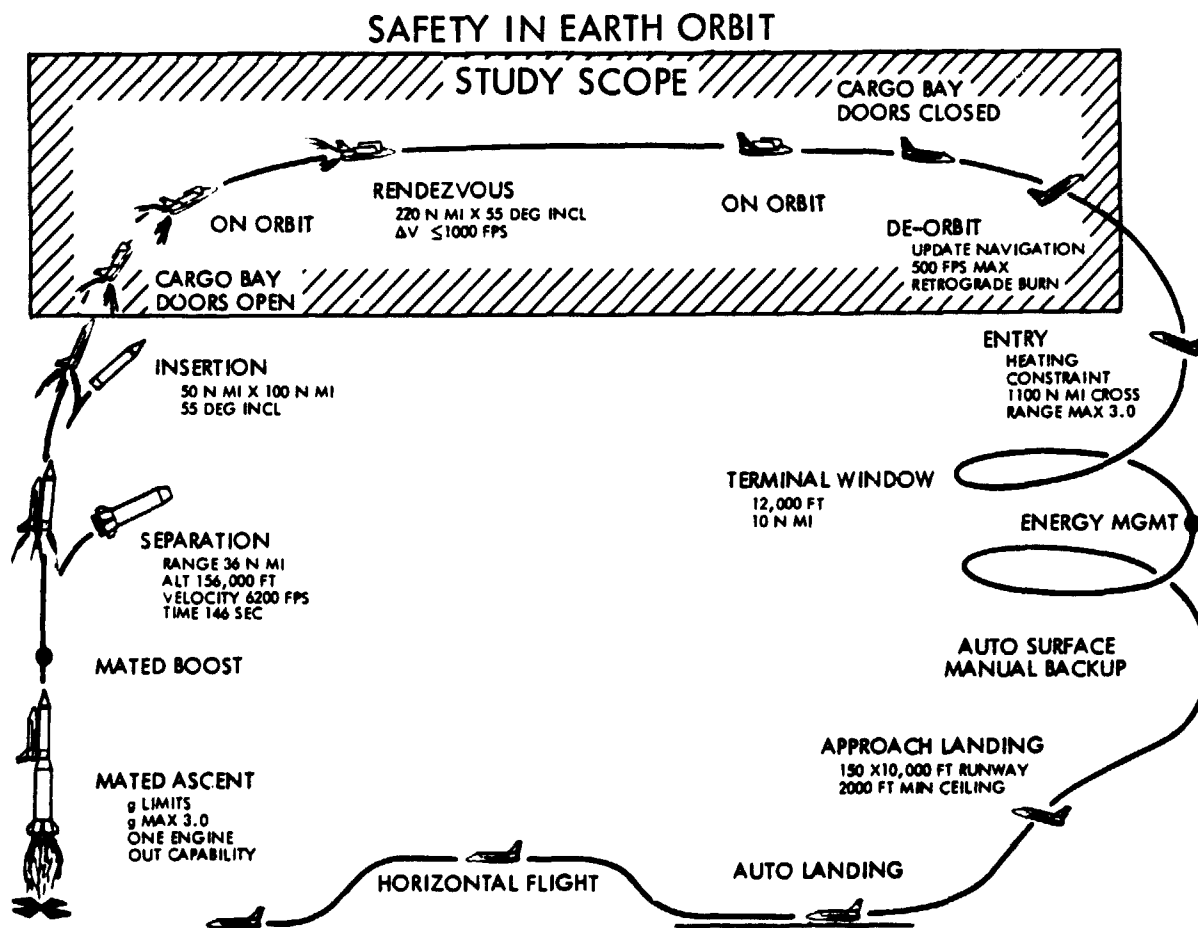


Figure 1-4. Typical Shuttle Mission



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At launch ( $t_0$ ) the orbiter and booster are mated and remain mated until staging, at which time separation occurs and the booster flies back to a landing site, while the orbiter initiates a main engine burn to effect injection into a 93 by 185 km (50 by 100 n mi) orbit at approximately  $t_0 + 9$  minutes. Immediately after post-insertion checks on orbiter subsystems, the orbiter cargo bay doors are opened to expose the orbiter space radiators on the inside of the cargo bay doors to space. This occurs at approximately 9 to 40 minutes after launch. At approximately 50 minutes, the apogee of the 93 by 185 km (50 x 100 n mi) orbit is obtained and a circularization burn is performed to circularize the orbiter in the 185 km (100 n mi) phasing orbit. After initial phasing relative to the target vehicle is accomplished, rendezvous and phasing adjustments are made during a series of Hohmann transfer burns to a circular orbit approximately 18.5 km (10 n mi) below the target vehicle. Final phase adjustments are made prior to initiating the terminal phase initiation burn to complete the rendezvous, station-keeping, and docking operations.

During the subsequent on-orbit staytime at the target vehicle orbit, the orbiter can either be attached to or can station-keep at a safe distance from the target vehicle.

Shortly before deorbit, phasing with a landing site is accomplished, system checks are made, and the cargo bay doors are closed. The deorbit burn which follows will result in entry to the earth's atmosphere at approximately 122 km (400,000 feet) and subsequent approach and landing at the preselected landing site.

It is significant to note that the orbiter cargo bay doors would be closed for only 1/2 hour to 1 hour while on orbit for a shuttle mission of any duration.

#### 1.4.2 Typical Orbiter Model

The primary orbiter concepts considered in the study are shown in Figures 1-5 and 1-6. The integral tank orbiter concept resulting from NR Phase B shuttle studies is shown in Figure 1-6 and includes such features as a 4.6 m 15-ft-diameter by 18.3 m 60-ft-length cargo bay with hinged cargo bay doors, two manipulators with peripheral illumination, visual and operating aids, a manipulator operator station, and an airlock docking port which interfaces with the crew and passenger compartments and with a personnel transfer port leading to the cargo bay. This configuration includes integral  $LH_2$  and  $LO_2$  propellant tanks for the main propulsion system used for orbit injection, and the auxiliary propulsion system used for orbit maneuvering and attitude control. An air-breathing propulsion system, which employs JP fuel and turbofan engines, is incorporated to provide the capability for short-duration powered descent after vehicle entry, powered landing and go-around, and vehicle ferry operations.

The drop tank orbiter configuration resulting from NR Phase B extension studies is shown in Figure 1-6 and differs from the previous configuration primarily in that it features an external jettisonable  $LO_2/LH_2$  ascent propellant tank, employs storable hypergolic propellants (nitrogen tetroxide and Aerozine 50) for the orbit maneuvering and attitude control systems. It is a lighter vehicle than the integral tank orbiter with a geometry which required relocation of the airlock docking port to the nose of the vehicle.



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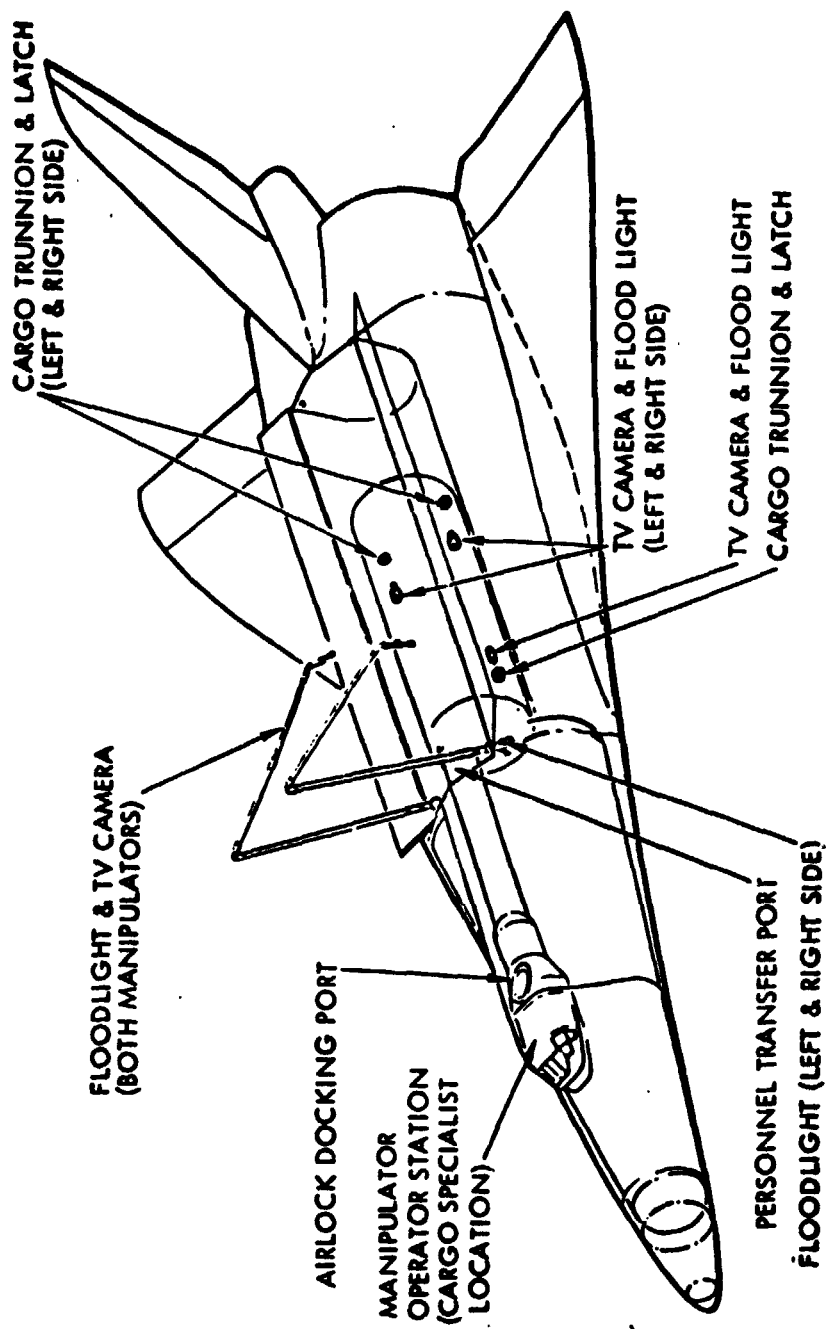
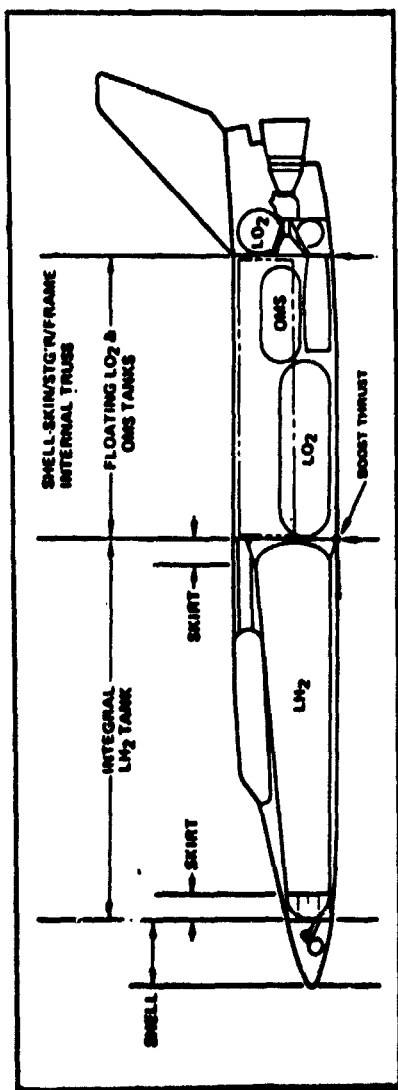


Figure 1-5. Integral Tank Orbiter Concept

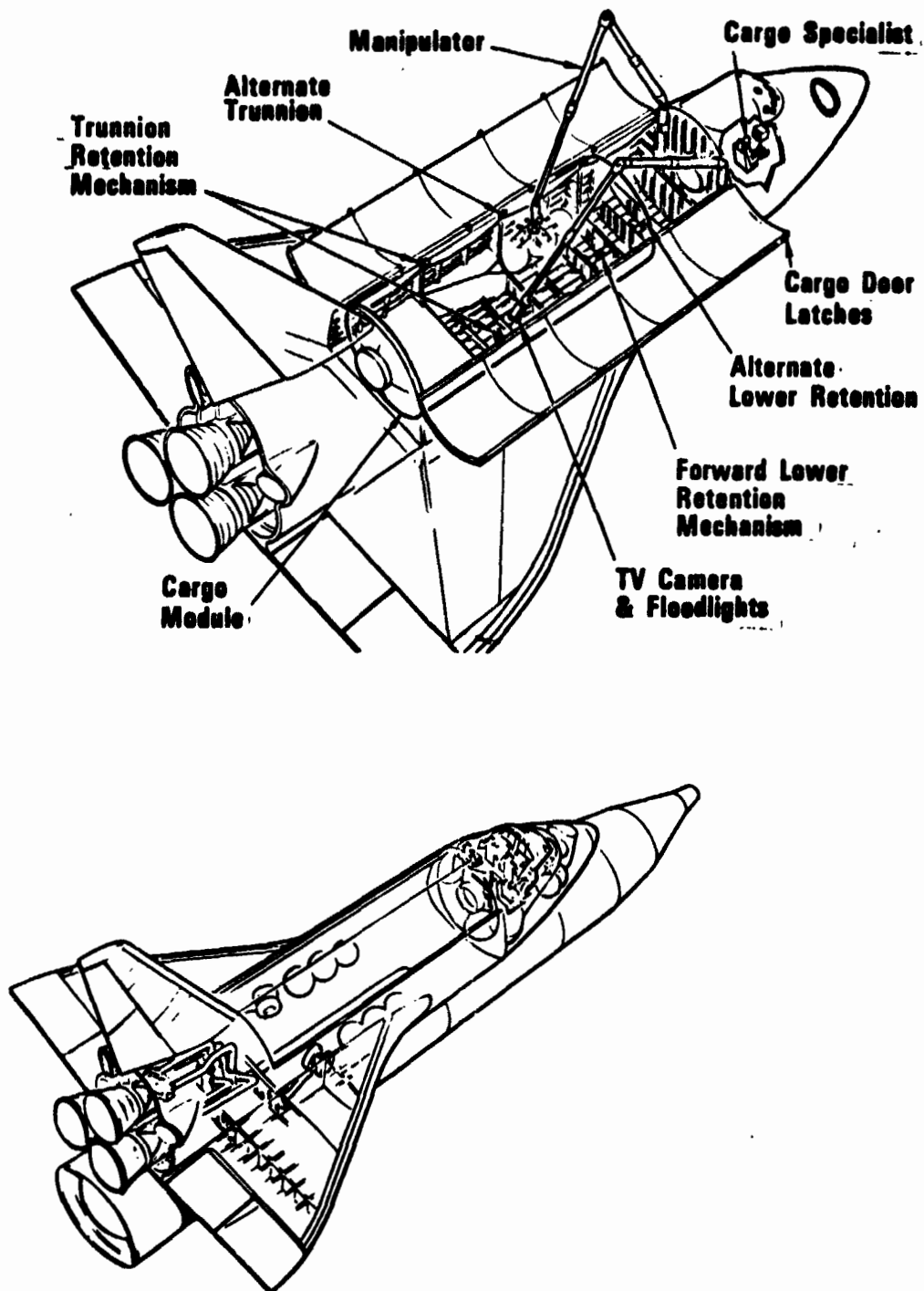


Figure 1-6. Drop Tank Orbiter Concept

The initial MDAC orbiter concept, which is similar to the NR integral tank orbiter, also employs integral LO<sub>2</sub> and LH<sub>2</sub> propellant tanks. However, a rotation payload deployment mechanism concept is used in lieu of an articulating manipulator, as shown in Figure 1-7.

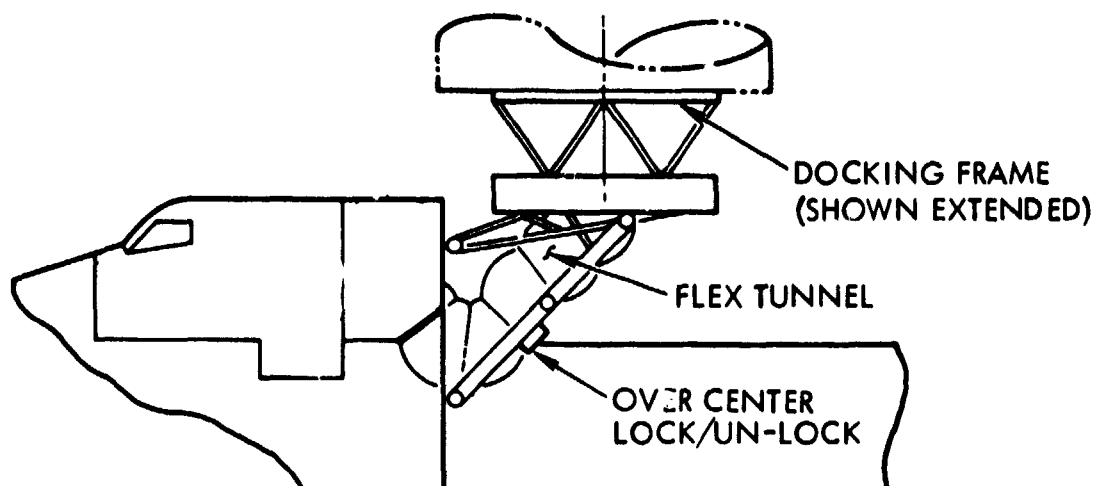


Figure 1-7. MDAC Payload Deployment Mechanism

#### 1.4.3 Typical Orbiter Payloads

Orbiter payloads considered in the study include the following:

1. Unmanned pallet-type sortie payloads, which remain attached to the orbiter. These may remain in the cargo bay, or be deployed out of it for exposure to space.
2. Manned sortie modules, which remain attached to the orbiter. These also may remain in the cargo bay, or be deployed out of it during orbital operations. These may be flown combined with an unmanned pallet payload.
3. Automated payloads. These include satellites and subsatellites delivered to orbit by the orbiter and operate detached from the orbiter. These also can be retrieved for servicing or return to earth.
4. Upper stage vehicles with their payloads. These are used as a shuttle third stage to deliver payloads beyond the orbiter's capability. The upper stage vehicles considered as candidates include:
  - o Agena
  - o Centaur
  - o Burner II
  - o Transtage
  - o Apollo service module (SM)
  - o Tug or orbit-to-orbit shuttle (OOS)





The Centaur, tug, and OOS, and possibly the SM, are considered reusable and may be retrieved. The others are expendable. These include the modules required for buildup of the permanent station, cargo modules for logistics resupply, experiment modules, and replacement modules as required. All these modules are returnable to earth in the orbiter.

#### 1.4.4 Typical Space Station Model

The primary modular space station (MSS) concepts being considered by NR and MDAC for the initial station are shown in Figures 1-8 and 1-9. As shown in Figure 1-8, the NR initial station consists of nine modules requiring a like number of shuttle flights for the station buildup. Similar data for the MDAC initial modular station are presented in Figure 1-9.

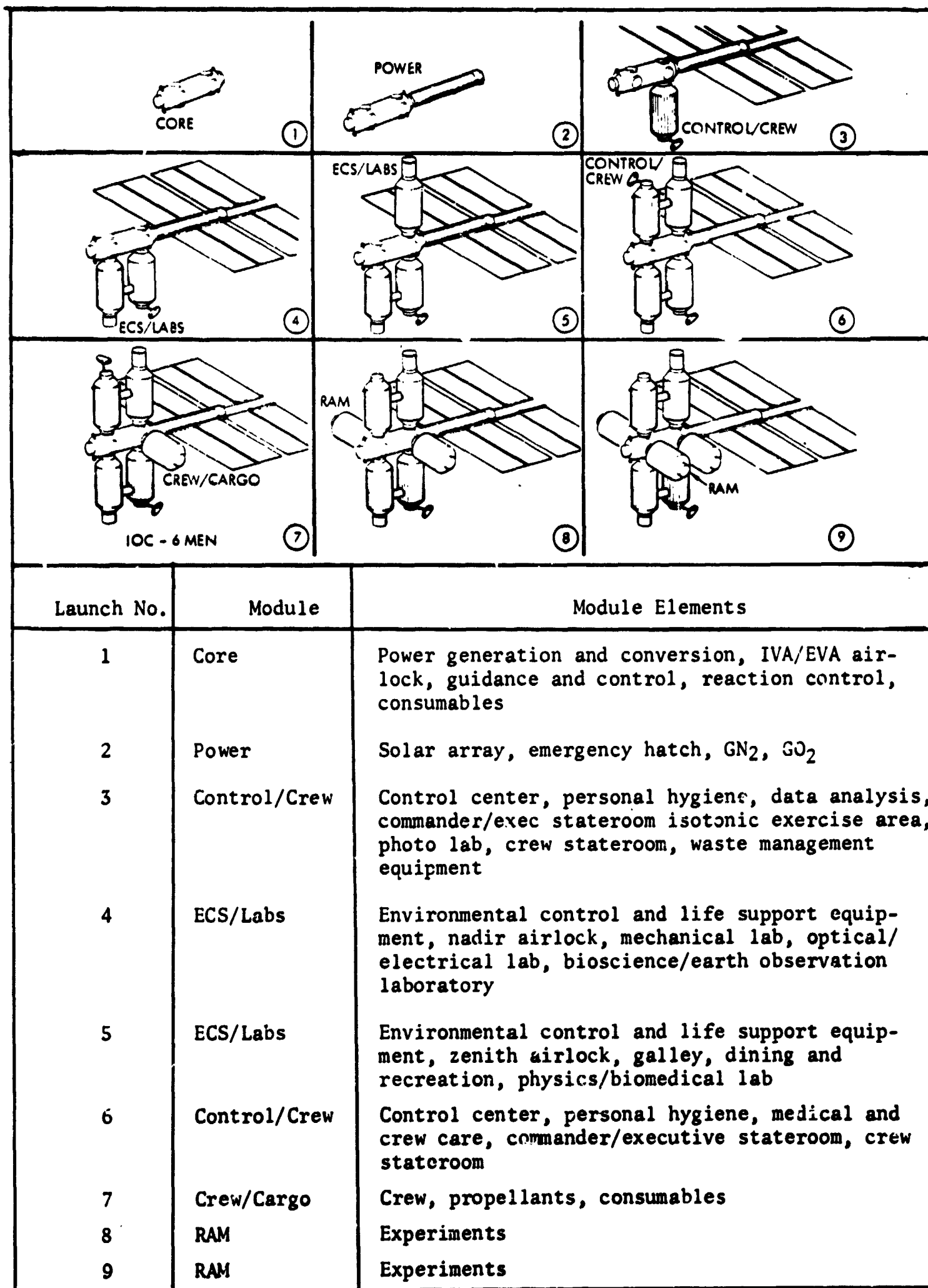
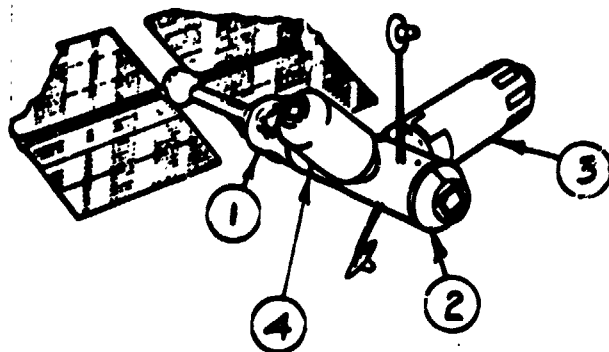


Figure 1-8. NR Modular Space Station



Launch No.	Module	Module Elements
1	Power/Subsystems	Solar array, propellant tankage, system communication, data management, displays/controls, onboard checkout, pump-down accumulator, atmosphere supply, control moment gyros, guidance and control, horizon sensor, electrical power supply, reaction control
2	Crew/Operations Module	Crew quarters, electronics, hygiene, command control console, galley/wardroom, crew quarters, food storage
3	General Purpose Laboratory	Data evaluation, secondary and experiment control consoles, airlock chamber and controls, biomedical lab, optical lab, isolation and test lab, EVA airlock, airlock chamber, mechanical sciences lab, hard data processing facility, electrical/electronics lab
4	Logistics Module	Propellant cargo, liquid and gas cargo, solid cargo, cargo handling aids, crew transfer tunnel, and airlock

**Figure 1-9. MDAC MSS Buildup Sequence/Initial Station**



## 2.0 HAZARDOUS EARTH ORBITAL SHUTTLE PAYLOADS, CARGO TRANSFER, AND HANDLING

Many different kinds of payloads will be carried into orbit in the orbiter cargo bay. The purpose of this task was to identify, analyze, and recommend solutions of the hazards resulting from (a) the delivery, deployment, and retrieval of hazardous payloads, and from (b) the transfer and handling of general types of cargo. Three particular areas of concern were investigated since they concern the safety of the orbiter and its crew and passengers while in orbit. These areas and the sections in which they appear are:

- Upper stage vehicles as they are transported in the orbiter cargo bay, deployed, and retrieved. These vehicles include expendable stages, mainly using storable or solid propellants, and reusable cryogenic stages. Hazards specific to on-orbit orbiter aborts are included. (Section 2.1)
- Hazardous fluid vessels transported and off-loaded in earth orbit in the orbiter as cargo or as part of a payload. Orbiter on-orbit abort hazards are included. (Section 2.2)
- The handling and transport of cargo between the orbiter, sortie modules, and Space Station. (Section 2.3)

The technical analyses for these three subtasks are reported in Sections 2.1, 2.2, and 2.3, respectively. Section 2.5 summarizes the residual hazards from this task and how they are resolved. Hazard/emergency analyses are contained in Appendix D of this volume.

The primary output of this task is the set of recommended requirements and guidelines. These are contained in Volumes IV and V of this report. A set of conclusions, based on the hazard/emergency analyses and the other supporting analyses of Appendix A, is given in Section 2.4, together with the supporting rationale.

It is believed that the assumptions inherent in this task are few and simple. These are:

- The Shuttle orbiter has the capability to operate in earth orbit independently of other vehicles in orbit, of the payload, or of the ground.



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- The orbiter has the inherent capability to return to earth with all its crew and passengers.
- The orbiter payload or payloads are carried in a single cargo bay. This cargo bay is protected during boost and reentry by a cargo bay door or doors, which form a part of the orbiter, and can be opened and closed by the orbiter crew. The cargo bay is not pressurized or pressurizable in orbit.
- The orbiter has the capability to deploy payloads out of the cargo bay, when required, and to retrieve and stow recoverable modules and payloads.
- The orbiter and Space Station have docking capability.

So long as these assumptions remain valid, the results of this task should be applicable. In addition, assumptions applicable to specific hazards/emergency analyses have been recorded individually in the particular analyses (see Appendix D).

## 2.1 UPPER STAGE VEHICLES AS SHUTTLE PAYLOADS

The purpose of this subtask was to identify the hazards associated with the transportation, deployment, and retrieval in earth orbit of upper stage vehicles, and to determine the safety measures required to deal with these. Both expendable stages and reusable stages were considered. The orbiter on-orbit abort hazards subsequent to these types of payloads were also analyzed.

A large range of upper stage vehicles is currently being considered for use in the shuttle orbiter. These stages will be used to launch unmanned payloads into higher orbits than the orbiter capability. Both existing vehicles such as the Agena and Centaur, modified existing vehicles such as Agena's and Centaur's with larger tanks, and new vehicles such as orbit-to-orbit shuttle (OOS) and the tug, are being considered. In general, only the cryogenic stages (Centaur, OOS and tug) are being considered reusable, but the Apollo service module could also be reusable. In addition to the liquid propellant stages, a solid propellant stage (Burner II) was also considered in the study as typical of solid stages.

Sections 2.1.1 and 2.1.2 identify potential hazards. Appendix A contains some specific supporting analyses. The hazard/emergency analyses and the resulting requirements and guidelines are contained in Appendix D and in Volumes IV and V of this report.



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### 2.1.1 Hazardous Elements of Upper Stage Vehicles

The upper stage vehicles considered in this subtask were:

- Agena
- Centaur
- Transtage
- Burner II
- Apollo service module
- Orbit-to-orbit Shuttle (OOS)/tug

It is believed that the hazards identified from these vehicles are typical of all upper stage vehicles that may be carried in the Shuttle orbiter in the foreseeable future. The modified versions of the Agena and the Centaur as presently conceived differ only in the sizing of the tanks. The subsystems will be the same as on the current stages. The OOS and the tug at the time this report was prepared were in Phase A Definition and therefore exact data on the subsystems to be used are not available. However, the results of the Phase A studies at North American indicate that the OOS/tug hazards are fully covered by the other vehicles considered.

Hazardous elements of the upper stage vehicles considered are listed in Table 2-1.

### 2.1.2 Identified Hazards

Potential hazards were identified by considering the hazardous elements of each upper stage vehicle (Section 2.1.1) and potential failure modes as applicable to each operation (Appendix A). These potential hazards are listed for each upper stage vehicle in Tables A-4 through A-8, listed by mission phase. Because of lack of detailed hardware definition, hazards for the OOS/tug have not been identified in this detail, but the Centaur hazards may be regarded as typical of the OOS/tug.

The individual hazards (identified in Tables A-4 through A-8 of Appendix A) were consolidated into 15 classes of hazards, applicable in general to all the upper stage vehicles. The hazard/emergency analyses of Appendix D of this report were performed for each of these classes of hazards.

These 15 classes of hazards are:

- 1.1.001 Explosion/rupture of a pressurized container in an upper stage vehicle inside or near orbiter.

- 1. 1. 002    Combination of mutually reactive upper stage vehicle fluids leading to explosion or fire inside or near orbiter.
- 1. 1. 003    Inadvertent detonation of explosive charge on upper stage vehicle inside or near orbiter.
- 1. 1. 004    Rapid decomposition of monopropellants located in or leaking from the upper stage vehicle while inside or near orbiter.
- 1. 1. 005    Uncontrolled combustion in active upper stage vehicle reaction control engines while near the orbiter.
- 1. 1. 006    Leakage of corrosive fluids from upper stage vehicle tanks while inside the orbiter.
- 1. 1. 007    Inadvertent start of an upper stage vehicle main or reaction control rocket engine while inside orbiter cargo bay.
- 1. 1. 008    Inadvertent separation of an upper stage vehicle attach point while in the orbiter.
- 1. 1. 009    Loss of attitude/translation control of upper stage vehicle upon release from orbiter.
- 1. 1. 010    Hangup of upper stage vehicle during release from orbiter.
- 1. 1. 011    Rupture of common bulkhead tanks in upper stage vehicle while in or near orbiter.
- 1. 1. 012    Loss of pressurization in pressure stabilized upper stage vehicle structure while in or near orbiter.
- 1. 1. 013    Inability to dump propellants or pressurants in retrieved upper stage vehicle.
- 1. 1. 014    Inability to dump upper stage vehicle propellants or pressurants during orbiter abort.
- 1. 1. 015    Inability to close cargo bay doors after retrieval of upper stage vehicle because of interference with upper stage vehicle.

The numbers refer to the hazard/emergency analyses in Appendix D of this report, in which these are analyzed.



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Table 2-1. Hazardous Elements of Upper Stage Vehicles

	Agena	Centaur	Transtage	Burner II	SM	OOS/Tug
<u>Fluid Propellants:</u>						
Nitrogen Tetroxide			X		X	
Aerozene -50			X		X	
Hydrogen Peroxide		X		X		
Liquid Oxygen		X			X	X
Liquid Hydrogen		X			X	X
Monomethyl Hydrazine					X	
Water/Glycol					X	
Unsymmetrical Dimethyl Hydrazine	X					
Inhibited Red Fuming Nitric Acid	X					
<u>Pressurized Containers:</u>						
Helium Tanks	X	X	X		X	X
Nitrogen Tanks	X		X	X	X	
Nitrogen Tetroxide Tanks			X		X	
Aerozene -50 Tanks			X		X	
Hydrogen Peroxide Tanks		X		X		
Liquid Oxygen Tanks		X			X	X
Liquid Hydrogen Tanks		X			X	X
Monomethyl Hydrazine Tanks					X	
Water/Glycol Tanks					X	
Unsymmetrical Dimethyl Hydrazine	X					
Inhibited Red Fuming Nitric Acid	X					
<u>RCS Propellants:</u>						
Aerozene -50 + Nitrogen Tetroxide			X			
Monomethyl Hydrazine + Nitrogen Tetroxide					X	
Hydrogen Gas + Nitrogen Tetroxide						X
<u>Corrosive Fluids:</u>						
Nitrogen Tetroxide			X		X	
Hydrogen Peroxide		X		X		
Liquid Oxygen		X			X	X
Inhibited Red Fuming Nitric Acid	X					



Table 2-1. Hazardous Elements of Upper Stage Vehicles (Cont)

	Agena	Centaur	Transtage	Burner II	SM	OOS/Tug
<u>Pyrotechnics:</u>						
Connections Between Modules-Cutters					X	
Helium Valves	X		X			
Solid Propellant Igniters				X		
Turbine Start Solid Propellant Charges	X					
Explosive Bolts - Payload Separation	X	X	X	X	X	X
Linear Shaped Charge - Panel Separation	X	X			X	
Destruct Shaped Charges	X	X	X	X	X	X
External Extensions - Antennae					X	
<u>Rocket Engines:</u> (Qty. Indicated)						
Main Engine	1	2	2	1	1	1-4
RCS Engine		8	12	4	16	20
<u>Stability Source:</u>						
Gyro Reference	X	X		X		X
Accelerometers	X	X				
Computer/Flight Control	X	X		X		X
<u>Attachment Methods:</u>						
Explosive Bolts				X		
Linear Shaped Charge	X	X	X		X	
Not Defined						X
<u>Attitude Hold/Translation Capabilities:</u>						
Translation - Main Engine	X(1)*	X(1)	X(1)	X(1)	X(1)	X(1)
-RCS			X(1)	X(2)	X(6)	X(6)
- Auxiliary		X(1)				
Attitude Hold - RCS Couples					X	
- Off-Center	X	X	X	X		
* ( ) Number of directions						

## 2.2 HAZARDOUS FLUID VESSELS AS SHUTTLE PAYLOADS

The purpose of this subtask was to identify the hazards associated with the various fluid vessels which may be transported in the Shuttle orbiter cargo bay as part of a payload, and to determine the safety requirements and guidelines to deal with these hazards.

In general, hazards exist either because the fluid is inherently hazardous, e. g., toxic or corrosive, or because of the conditions under which it is transported; e. g., at high pressure or as a cryogen. The Shuttle crew or passengers are normally only directly exposed to the hazard when a manned, pressurized experiments module is carried on the orbiter as part of a sortie module. Situations in which crew or passengers have exposed themselves to the hazardous fluids in extravehicular activity (EVA) have also been considered. The main safety concern has turned out to involve damage to the orbiter, particularly the cargo bay area; and this, of course, jeopardizes personnel safety indirectly by precluding return to earth.

A major area not covered in this study is the transportation into space by the Shuttle of large quantities of propellants for logistic resupply of such vehicles as a tug, orbital propellant depot, and chemical or nuclear propulsion stages. The reason is that the entire subject of logistics resupply of propellants and propellant transfer is being studied in a concurrent NASA study at the Space Division, In-Space Propellant Logistics and Safety Study, Contract NAS8-27692. Project II of this study is specifically concerned with the safety aspects.

Sections 2.2.1 to 2.2.4 identify hazardous fluids involved in the orbiter payloads (except upper stage vehicles, which were covered in Section 2.1). Section 2.2.5 summarizes the hazards, and the remaining sections contain some specific supporting analyses. The hazard/emergency analyses are contained in Appendix D and the resulting requirements and guidelines in Volume IV and V of this report.

### 2.2.1 Hazardous Experiment Fluids

Hazardous experiment fluids were identified by a review of Volumes II through VIII of the Blue Book, Preliminary Edition of Reference Earth Orbital Research and Applications Investigations, 15 January 1971. This document was selected because it is used as a baseline NASA document to define a manned spaceflight research capability to be conducted in Earth Orbital Space Stations and Shuttles and is therefore not oriented specifically to any single program. The eight Blue Book volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics



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Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences and Maintenance
Volume VII	Technology
Volume VIII	Life Sciences

The results of the Blue Book review are listed in Tables A-9 through A-15 of Appendix A. The experiment and subexperiment for each discipline are listed together with the subexperiment basic fluid requirements. (The tables also include materials which were identified and listed for use in other tasks.) Container quantities, pressures, and volumes are indicated when specified. Worthy of particular note is the potential use of mercury for the quantum effects at low temperature and zero g physics experiments, and a requirement in excess of 1100 kg (2500 lb) of LH<sub>2</sub> to support long-term cryogenic storage technology experiments.

#### 2.2.2 Hazardous Sortie Module Fluids

Sortie modules include research and applications module (RAM), RAM support module (RSM), mission support module (MSM), and palletized experiment payloads which remain attached to the orbiter and are used as reusable space laboratories or support facilities.

Because of the level of detail available from the current Shuttle Orbital Applications/Requirements (SOAR) and research and applications module studies, it was not possible to identify specific hazardous fluids associated with all program elements. However, since for normal sortie missions these modules will be attached to the orbiter, and the orbiter will provide necessary experiment attitude control and propulsion, propellants are not required in these modules. A possible exception may exist if the RSM or MSM is used to service and refuel automated payloads, in which case significant quantities of propellants would be required. The RSM will provide environmental control and life support facilities for the experiment crew in addition to providing facilities to support the conduct of experiments. For a typical seven-day experiment sortie mission, it will require fluids in the approximate quantities and with approximate container characteristics as listed in Table 2-2.

Table 2-2. RAM Support Module Fluids for Seven-Day Mission

Fluid	Fluid Quantity Kg (lb)	Container Volume M <sup>3</sup> (ft <sup>3</sup> )	No. of Containers
LO	310(680)	0.23 (7.1)	2
LH	34(75)	0.36 (12.6)	2
LN <sub>2</sub>	60(133)	0.23 (8.1)	1
GN <sub>2</sub>	4.5(10)	Not defined	Not defined

Hazardous fluids other than those applicable to sortie missions which were identified during review of the 1971 NASA Experiment Blue Book were not identifiable.

### 2.2.3 Hazardous Station Fluids

Hazardous fluids are required by both the SD and McDonnell Douglas (MDAC) designs of the Modular Space Stations during the station buildup and normal operations phases. Station modules containing hazardous fluids for attitude control, electrical power generation, and pressurization will be delivered by the Shuttle during the buildup phase. Resupply of station subsystem consumables will be accomplished under the present concepts via an orbiter delivered cargo or logistics module.

The SD station is planned to generate  $\text{GO}_2$  and  $\text{GH}_2$  by water electrolysis during normal operations. During buildup, it requires delivery of high-pressure gases on the initial modules to support subsequent buildup operations. After station buildup, delivery of water for electrolysis and  $\text{GN}_2$  for atmosphere leakage makeup via the cargo module will be the primary station subsystem resupply fluids. The expected fluid quantities, tank quantities, and pressures for the SD station core and power module buildup launches and the cargo module resupply for station subsystems are shown in Table 2-3. This includes fluid quantities required for station repressurization, EVA support, and 48-hour emergency support.

Table 2-3. Expected Hazardous Fluids - NR Modular Station Subsystems

	CORE MODULE			POWER MODULE			CARGO MODULE		
	Container Characteristics			Container Characteristics			Container Characteristics		
Fluid	Fluid Qty Kg(1b)	Qty	Vol M <sup>3</sup> (ft <sup>3</sup> )	Fluid Qty Kg(1b)	Qty	Vol M <sup>3</sup> (ft <sup>3</sup> )	Fluid Qty Kg(1b)	Qty	Vol M <sup>3</sup> (ft <sup>3</sup> )
GO <sub>2</sub>	146(322)	4	.15(5.3)	125(274)	3	.15(5.3)	88(194)	2	.31(10.9)
				88(194)	3	.31(10.9)	64(141)	1	.22(7.9)
GH <sub>2</sub>	18(40)	4	.31(10.9)	15(34)	3	.31(10.9)	3.2(7)	3	.21(7.6)
GN <sub>2</sub>				58(127)	3	.24(8.6)	73(161)	6	.31(10.9)
All pressures $2.06 \times 10^7 \text{ N/m}^2$ (3000 psi).									



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On the MDAC station, significant quantities [approximately 106 kg/month (233 lb/month) for three months] of  $\text{N}_2\text{H}_4$  (hydrazine) will be required on the initial power/subsystems module launch to provide station attitude and maneuver control prior to the installation of control moment gyros (CMG's) and before the activation of resistojets which require  $\text{CO}_2$  (carbon dioxide) in quantities capable of being generated by the crew. High-pressure atmospheric supply bottles of  $\text{GO}_2$  and  $\text{GN}_2$  in significant quantities are also intended to be contained in the power/subsystems module. Resupply of the station, after initiation of the resistojet system, will require smaller quantities of  $\text{N}_2\text{H}_4$  than those required on the initial launch, but will require substantial quantities of high-pressure  $\text{GO}_2$  and  $\text{GN}_2$  for atmospheric leakage resupply.

#### 2.2.4 Hazardous Automated Payload Fluids

Automated payloads are capable of being operated in a free-flying mode after release from the orbiter. The automated payloads range in size from a 136 kg (300 lb) earth orbiting small applications technology satellite to a 11,400 kg (25,000 lb) high energy astronomical observatory (HEAO) in low earth orbit. When an upper stage vehicle is required, as for automated planetary payloads, the payload total weights can approach the maximum payload of 29,500 kg (65,000 lb), of which approximately 70 percent is propellants. While propellant quantities for small satellites of the 136 kg (300 lb) class are not considered significant, propellant requirements for attitude control and orbit makeup of large low earth orbit payloads, such as the HEAO, can be significant. Although cryogenic oxygen and hydrogen could be used for propulsion for short duration automated payload missions, it is more likely that solid propellants and storable propellants such as cold gas  $\text{GN}_2$ , monopropellants such as hydrazine, A-50, hydrogen peroxide, and monomethyl hydrazine, and hypergolic or ignitable bipropellants will be employed. Small quantities of cryogenics may be required, however, to cool experiment sensors, as in infrared astronomy experiments.

#### 2.2.5 Summary of Hazardous Fluid Vessels in Orbiter Payloads

Hazardous fluids identified for the upper stage vehicles, Blue Book experiments, Space Station, sortie modules, and automated payloads are summarized in Table 2-4 together with the hazardous characteristics of the fluid and accountability to the payload element.

#### 2.2.6 Identified Hazards

Each fluid vessel to be transported in the orbiter cargo bay is associated with a set of discrete hazards. This set depends on the hazardous properties of the fluid, the quantity of fluid, its storage conditions, its location in the orbiter, and the mode of operation (e.g., whether manned

Table 2-4. Summary of Hazardous Fluid Vessels in Orbiter Payloads

HAZARDOUS FLUID	HAZ. RD	PROGRAM ELEMENT			
		UPPER STAGE VEHICLE	BLUEBOOK EXPERIMENT	OTHER	
		Toxicity Fire Corrosion Explosive	Agna Centaur Burner II Transtage Service Mod./Apollo OOS/Tug	Astronomy Physics Earth Observation Comm./Nav. Mater. Sci. & Proc. Technology Life Sciences	Space Station (NR) Space Station (MDAC) RAM Support Module Automated Payload
<u>CRYOGENICS</u>					
LN <sub>2</sub>	B		X	X X	X
LO <sub>2</sub>	B X X X	X	X X	X	X
LHe	B			X X	
LH <sub>2</sub>	B X X	X	X X		X
Slush Hydrogen	B X X				
Solid Cryogen	B				
Undefined Cryogen	B				
LN <sub>e</sub>	B				
LA <sub>r</sub>	B				
Superfluid Helium	B				
Dry Ice (LCO <sub>2</sub> )	B				
<u>GAS</u>					
O <sub>2</sub>	X X X X			X X X	X X
N <sub>2</sub>	A	X X X X		X	X X X X
H <sub>2</sub>	X X X				X
Unspecified Gas				X	
He	A	X X X X		X X	
Hydrocarbons	X X			X	
Carbon Tetraflouride (CF <sub>4</sub> )	X			X	
Carbon Monoxide (CO)	X X X			X	
Carbon Dioxide (CO <sub>2</sub> )	A			X	X
Nitric Oxide (NO)	C X			X	
Acetylene (HC≡CH)	A X X			X	
Diborane (B <sub>2</sub> H <sub>6</sub> )	X X X			X	
Xenon (Xe)	C			X	
Footnotes: A = Simple asphyxiant B = Can cause severe burns and tissue damage on contact with skin C = Extremely toxic when heated to decomposition X = Applicable or present					



Table 2-4. Summary of Hazardous Fluid Vessels in Orbiter Payloads (Cont)

HAZARDOUS FLUID	HAZARD	PROGRAM ELEMENT			
		UPPER STAGE VEHICLE	BLUEBOOK EXPERIMENT	OTHER	
		Toxicity Fire Corrosion Explosive	Agna Centaur Burner II Transtage Service Mod./Apollo OOS/Tug	Astronomy Physics Earth Observation Comm./Nav. Mater. Sci. & Proc. Technology Life Sciences	Space Station (NR) Space Station (MDAC) RAM Support Module Automated Payload
<u>GAS</u> (Continued)					
Sulfur Hexaflouride (SF <sub>6</sub> )	C		X		
Methane (CH <sub>4</sub> )	A X X			X	
Propane (CH <sub>3</sub> CH <sub>2</sub> CH <sub>3</sub> )	X X X			X	
Unspecified Combustibles	X			X	
Hydrogen Sulfide (H <sub>2</sub> S)	C X X				
<u>LIQUID</u>					
Hydrazine (N <sub>2</sub> H <sub>4</sub> )	1 X X X		X	X	X X
Nuclear Emulsion			X		
Hydrocarbons	X X		X		
Trimethylaluminum (AL(CH <sub>3</sub> ) <sub>3</sub> )	X X X		X		
Freon	X		X	X	
Mercury	X		X		
Phenol (C <sub>6</sub> H <sub>5</sub> OH)	X X			X	
Formaldehyde	X X X			X	
Liquid Metals				X	
Potassium Sodium Niobate				X	
Potassium Sodium Silicate				X	
Solvent					
Gallium Arsenide Solution	X X X			X	
Liquid Gallium	X			X	
Fused Silicate Solutions				X	
Hexane (CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> CH <sub>3</sub> )	X X X				X
Methanol (CH <sub>3</sub> OH)	X X X				X
Pentane (CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> CH <sub>3</sub> )	X X X				X
Ethanol (CH <sub>3</sub> CH <sub>2</sub> OH)	X X X				X
Freon II	X				X
Freon II4B2	X				X
Freon 21	X				X
Glycol	X X X				X



Table 2-4. Summary of Hazardous Fluid Vessels in Orbiter Payloads (Cont)

HAZARDOUS FLUID	HAZARD	PROGRAM ELEMENT		
		UPPER STAGE VEHICLE	BLUEBOOK EXPERIMENT	OTHER
	Toxicity Fire Corrosion Explosive	Agena Centaur Burner II Transtage Service Mod./Apollo OOS/Tug	Astronomy Physics Earth Observation Comm./Nav. Mater. Sci. & Proc. Technology Life Sciences	Space Station (NR) Space Station (MDAC) RAM Support Module Automated Payload
<u>LIQUID</u> (Continued)				
IITRI ZNO Silicone (S-13)	X X		X	
IITRI ZNO Silicate (Z-9)	X X		X	
LMSC Thermatrol TL <sub>2</sub> Silicone (6A-100)	X X		X	
Schteldahl GT-1015	X X		X	
Lubricants	X X		X	
Hydroquinones	X X X			
C <sub>2</sub> H <sub>4</sub>	X			
Nitrogen Tetroxide (N <sub>2</sub> O <sub>4</sub> )	X X	X X X		X
A-50 (50% UDMH + 50% Hydrazine)	C X X X	X X X		X
Hydrogen Peroxide (H <sub>2</sub> O <sub>2</sub> )	X X X X	X X		X
Monomethyl Hydrazine	C X X X	X		X



or unmanned). In addition, further hazards may be introduced by the interaction of a fluid tank and a piece of Shuttle equipment (e. g., a water tank next to a high-temperature source), or by the colocation of two tanks, each of which is relatively safe on its own (e. g., O<sub>2</sub> and H<sub>2</sub> tanks next to each other).

Upon review of all the potential hazards, it was found possible to condense these into five generalized classes of hazard. For purposes of this study, it was found both practical and desirable to use the following classes as the hazard or emergency:

- 1.2.001 Exposure of the orbiter crew or passengers to a toxic environment released from a vessel in the payload containing a toxic fluid.
- 1.2.002 A fire in the cargo bay resulting from release and ignition of a flammable fluid in an unpressurized payload.
- 1.2.003 A fire in a pressurized payload in the cargo bay resulting from release and ignition of a flammable fluid.
- 1.2.004 A corrosive environment in the orbiter cargo bay resulting from leakage or rupture of a payload vessel containing a corrosive fluid.
- 1.2.005 An explosion in the orbiter cargo bay of a potentially explosive payload vessel.

The numbers refer to the hazard/emergency analyses in Appendix D of this report, in which these are analyzed.

Fluids stored in pressure vessels also present an explosion hazard. This type of explosion hazard is not indicated in Table 2-4, because this is a characteristic of the storage conditions and quantities rather than of the fluid. Every fluid stored as a gas, or as a liquid under pressure, exhibits this hazard to some extent or other (see Appendix A).

## 2.3 CARGO HANDLING AND TRANSPORTATION BETWEEN SHUTTLE ORBITER, SORTIE MODULES, AND SPACE STATION

The purpose of this subtask was to identify the hazards associated with the handling and transportation of cargo between the Shuttle orbiter, sortie modules, and Space Station in earth orbit, and to determine the safety requirements and guidelines to deal with these hazards.



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A review of the potential missions currently envisioned for the Shuttle in sortie modes, and later on for the Space Station, shows that a large and varied range of supplies will be transported into space by the Shuttle. Much of this cargo will be transferred from the Shuttle orbiter (the logistics supply vehicle) to the user vehicle (Space Station, sortie module, satellite, or reusable orbital propulsion stage). Some will be transferred from the orbiter in modular form, e. g., as a cargo module, as a module of a station, or as a prepackaged payload for a propulsion stage. Individual cargo packages, such as food supplies, experiments, subsystems modification kits, or spares and fluid resupply tanks, will in turn need to be transferred from some of these modules to their ultimate user location in other modules. In some cases, individual packages will be transferred, manually or mechanically, directly from the orbiter cargo bay to a user satellite or other spacecraft. And finally, return cargo to earth, such as data packages, empty tanks, waste material, and replaced components will be returned in similar ways from the user vehicles to the orbiter for return to earth.

This subtask is concerned with operations of all these cargo handling and transfer operations that involve discrete individual pieces of cargo. These transfers involve mainly the orbiter, sortie modules, and the Space Station. The transfer of complete modules or complete Shuttle payloads, such as upper stage vehicles and payloads, is not considered here (see Sections 2.1 and 3.0). The transfer of bulk quantities of propellants for the re-fuelling of space-based propulsion stages is not covered here. The design, operational, and safety aspects are being evaluated in a concurrent study at SD, In-Space Propellant Logistics and Safety Study, Contract NAS8-27692.

The cargo that may be handled and transferred is identified in Section 2.3.1; the traffic model (what cargo, from which vehicle, and to which vehicle) in Section 2.3.2; and potential cargo handling and transfer methods in Section 2.3.3. The potential hazards are identified in Section 2.3.4, and the remaining sections contain some specific supporting analyses. The hazards/emergency analyses and the resulting requirements and guidelines are contained in Appendix D of this volume, and in Volumes IV and V of this report.

### 2.3.1 Candidate Cargo

The candidate cargo materials to be handled and transferred between orbiter, sortie modules, and Space Station were derived from the logistics resupply requirements developed in the NR Phase B Space Station study. In this study the station was planned to complete the experiments contained in the NASA Experiments Blue Book, as well as logistically supply a crew of 6 to 12 men for up to 10 years in earth orbit. On-board experiments, attached and detached experiments modules, and free-flying satellite support were included in the operations. Since the current missions for the Shuttle

sortie missions are less ambitious than this, both in terms of experiments to be carried out and of number of man-months in orbit, the candidate cargo manifest for the Space Station includes all individual cargo (excluding satellites and propulsion stages) currently being considered for the Shuttle, sortie, and station programs.

The candidate list of cargo which was made up to define the cargo module characteristics extracted from Space Station Program Phase B Definition (Cargo Module Definition, DRL-47, North American Rockwell, Space Division, SD 70-5040, MSC-00759, January 1971), is listed in Table 2.5. Candidate items which are inherently or potentially hazardous are identified in this list by an asterisk.

A more complete identification of hazardous payload fluids, together with their hazardous characteristics, is included in Section 2.2 of this volume. In addition, nuclear safety considerations arise from some radioactive materials needed for specific experiments. Specific radioactive materials identified from the NASA Blue Book are discussed in Appendix A.

### 2.3.2 Cargo Handling and Transfer Model

Table 2-6 indicates the cargo transfer flow between spacecraft elements. The letters H or N indicate that cargo, hazardous or nonhazardous, respectively, is to be transferred from the element in the left-hand vertical column to the corresponding element in the top horizontal row. This analysis follows from the definition of the various program elements and from the NR Phase B Space Station operational model used in Section 2.3.1. In accordance with conclusions reached in the hazards/emergency analysis of this section, it has been assumed in this model that no hazardous cargo will be carried in or through the orbiter crew compartment or airlock. The analysis has shown that all cargo can be transported to space and transferred as required without violating this assumption.

### 2.3.3 Methods of Cargo Handling and Transfer

Many methods are available for the transfer of cargo. The main concepts for shirtsleeve transfer are shown in Figure 2-1, based on classifications defined by MDAC. These range from strictly hand-carry methods with no mechanical assists, to trolley systems that employ cages and remote controls. The MDAC concept of a cable guide system is categorized under manual-aided methods.

For solid cargo transfer between a pressurized environment and an unpressurized environment, such as camera film reloading and retrieval from an unpressurized pallet, an airlock would be required. In addition,

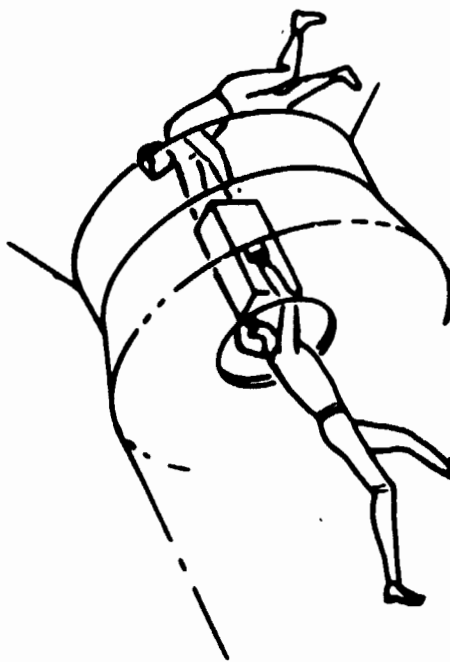
Table 2-5. Space Station Logistics Resupply

Cargo Item	Cargo Item
<ul style="list-style-type: none"> <li>* Liquid hydrogen</li> <li>* Liquid oxygen</li> <li>* Liquid nitrogen</li> <li>* Liquid helium</li> <li>* Miscellaneous cryo</li> <li>* Atmosphere</li> <li>* Argon</li> <li>* Neon</li> <li>* Helium</li> <li>* Carbon dioxide</li> <li>* Oxygen</li> <li>* Nitrogen</li> <li>* Calibration gas</li> <li>* Miscellaneous cryo</li> <li>Water-animals</li> <li>Water-no metallic content</li> <li>Water-sterile triple distilled</li> <li>Photo process chemicals</li> <li>Emulsion</li> <li>Chemicals</li> <li>Film-35 mm</li> <li>* Hydrazine</li> <li>Life support</li> <li>Service items</li> <li>Station spares</li> </ul>	<ul style="list-style-type: none"> <li>Film-35 mm cine</li> <li>Film-70 mm</li> <li>Film-150 mm</li> <li>Film-225 mm</li> <li>Film 16 mm</li> <li>Film-9 x 14 mm</li> <li>Cultures (food)</li> <li>Specimens and food</li> <li>Food (animals)</li> <li>Tape, video</li> <li>Tape, audio</li> <li>Tape and microfilm</li> <li>Magnetic tapes</li> <li>Specimens spares</li> <li>Logistics</li> <li>Micrometeroid collector</li> <li>Balloons</li> <li>Dry samples</li> <li>Diary, logistics</li> <li>Lab supplies</li> <li>Physiological Measurement supplies</li> <li>Accessories</li> <li>Film plates</li> <li>Probes</li> <li>Waste (return)</li> </ul>
* Hazardous Items	

**Table 2-6. Cargo Handling and Transfer Model**

	EOS <sup>+</sup> Crew Compartment or Airlock	*EOS <sup>+</sup> Propellant Tanks RAM Support Module	Experiment Pallet	RAM <sup>x</sup> (7-30 day sortie)	RAM <sup>x</sup> (free flyer)	Space Station	Space Station Cargo Module	Mission Support/Adapter Module	Upper Stage Vehicle	USV <sup>°</sup> Payload	EOS <sup>+</sup> Serviceable Automated Payload
EOS <sup>+</sup> Crew Compartment or Airlock	-	-N	N	N	N	N	N	N	-	-	N
*EOS <sup>+</sup> Propellant Tanks	-	--	H	H	H	H	H	H	H	H	H
RAM <sup>x</sup> Support Module	N	--	N,H	N,H	N,H	-	-	-	-	-	-
Experiment Pallet	N	-N	-	-	-	-	-	-	-	-	-
RAM <sup>x</sup> (7-30 Day Sortie)	N	-N	-	-	-	-	-	-	-	-	-
RAM <sup>x</sup> (Free Flyer)	N	-N	-	-	-	-	-	-	-	-	-
Space Station	N	--	-	-	-	-	N	-	-	-	-
Space Station Cargo Module	N	--	-	-	-	N,H	-	-	-	-	-
Mission Support/Adapter Module	N	H-	N,H	-	-	-	-	-	**N,H	-	**N,H
USV <sup>°</sup> (Upper Stage Vehicle)	N	--	-	-	-	-	-	N	-	N,H	-
USV <sup>°</sup> Payload	N	--	-	-	-	-	-	-	N	-	-
EOS <sup>+</sup> Serviceable Automated Payloads	N	--	-	-	-	-	-	N	-	-	-
<b>Legend:</b> N = Non-hazardous cargo (film, tape, service items) H = Hazardous cargo (propellants, hazardous fluids and materials) - = Not applicable or no cargo transfer  <b>Notes:</b> * Considers potential payload use of EOS reserve propellants ** Considers potential use of EOS propellants stored in cargo bay to extend EOS capability + EOS = Earth Orbital Shuttle (orbiter) x RAM = Research Applications Module (sortie module) ° USV = Upper Stage Vehicle											

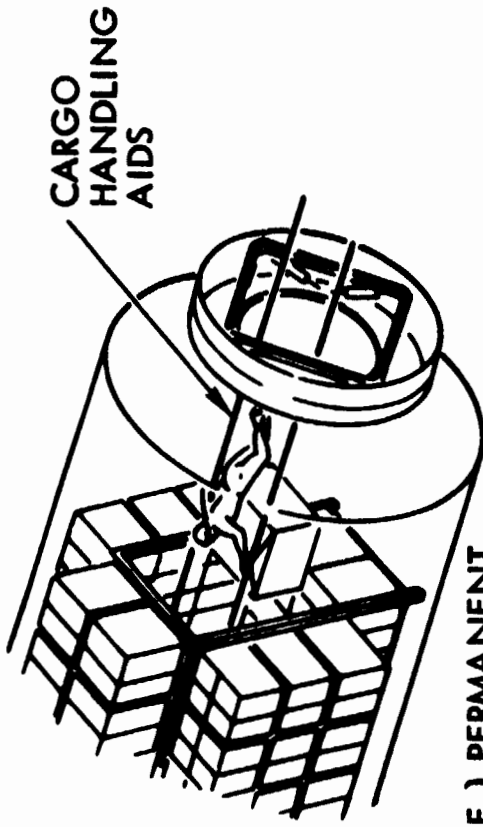
● MANUAL UNAIDED



- COMMON CONTAINERS
- COMMON HANDLES
- APOLLO
- SKYLAB (MAX PKG WT = 160 LB)

● MANUAL AIDED

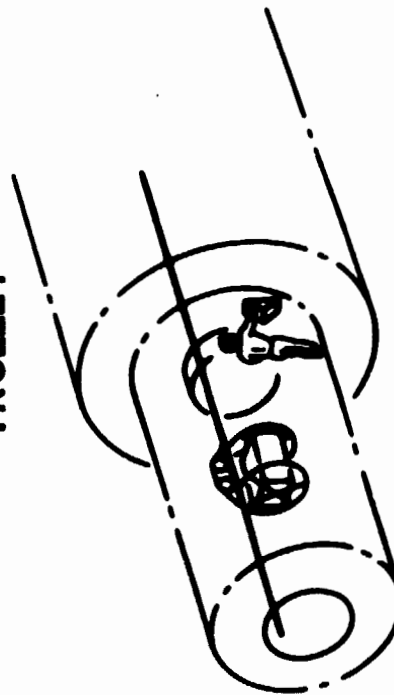
CABLE OR RAIL GUIDES



- SINGLE } PERMANENT
- DUAL } REMOVABLE

● MECHANICAL TRANSFER

TROLLEY



- MANUAL (PULLEY)
- AUTOMATIC

EXTENSION BOOM

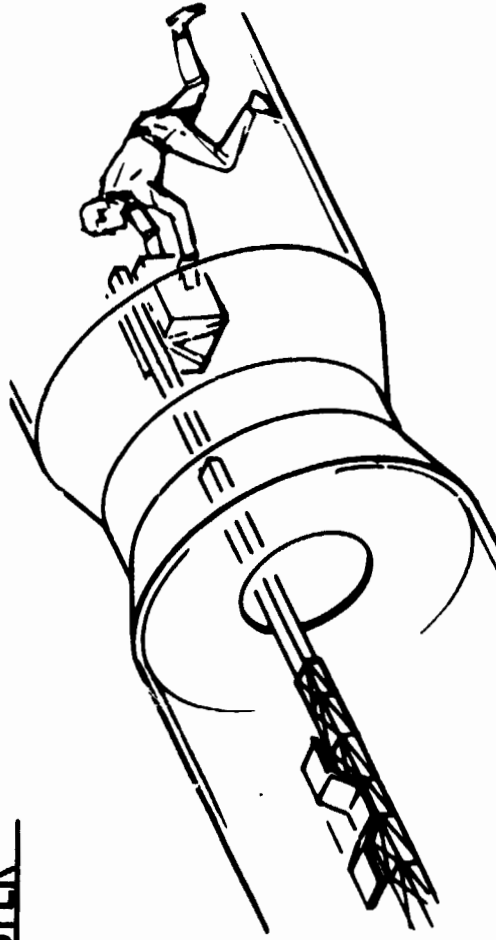


Figure 2-1. Cargo Handling and Transfer Methods



intravehicular and extravehicular activity (IVA and EVA) would be involved if the cargo transfer were performed manually. Use of manipulators attached to the orbiter, such as shown in Figure 2-2, small specialized manipulators attached to a manned payload module, and other mechanisms controllable from a shirtsleeve environment are being considered to avoid IVA and EVA. The small specialized manipulators would provide dexterity, positioning accuracy, and control capability in excess of the larger Shuttle manipulator.

Two basic alternatives available for the transfer of fluids are bulk transfer in self-contained tanks, and plumbed transfer in which fluids are pumped from one fixed container to another across an interfacing element such as a docking port.

#### **2.3.4 Identified Hazards**

Potential hazards which can occur during cargo handling and transfer operations were identified by considering possible combinations of the following:

- Candidate cargo, both hazardous and non-hazardous, from Section 2.3.1.
- The cargo handling and transfer model of Section 2.3.2.
- The different methods of cargo handling and transfer discussed in Section 2.3.3.

The hazards or emergencies were considered to arise from two sources, as follows:

- Failures or accidents related to hazardous cargo items from Section 2.3.1 in otherwise normal handling and transfer operations.
- Malfunctions, failures, or accidents related to the cargo handling and transfer mechanisms, including human errors, considering both hazardous and nonhazardous cargo.

The resulting hazards and emergencies were grouped into five generalized hazard/emergencies, which cover all the individual situations to the level of detail appropriate to this study. These hazards/emergencies are:

- 1.3.001 Spillage or leakage of hazardous fluid or material during manual transfer in pressurized modules.



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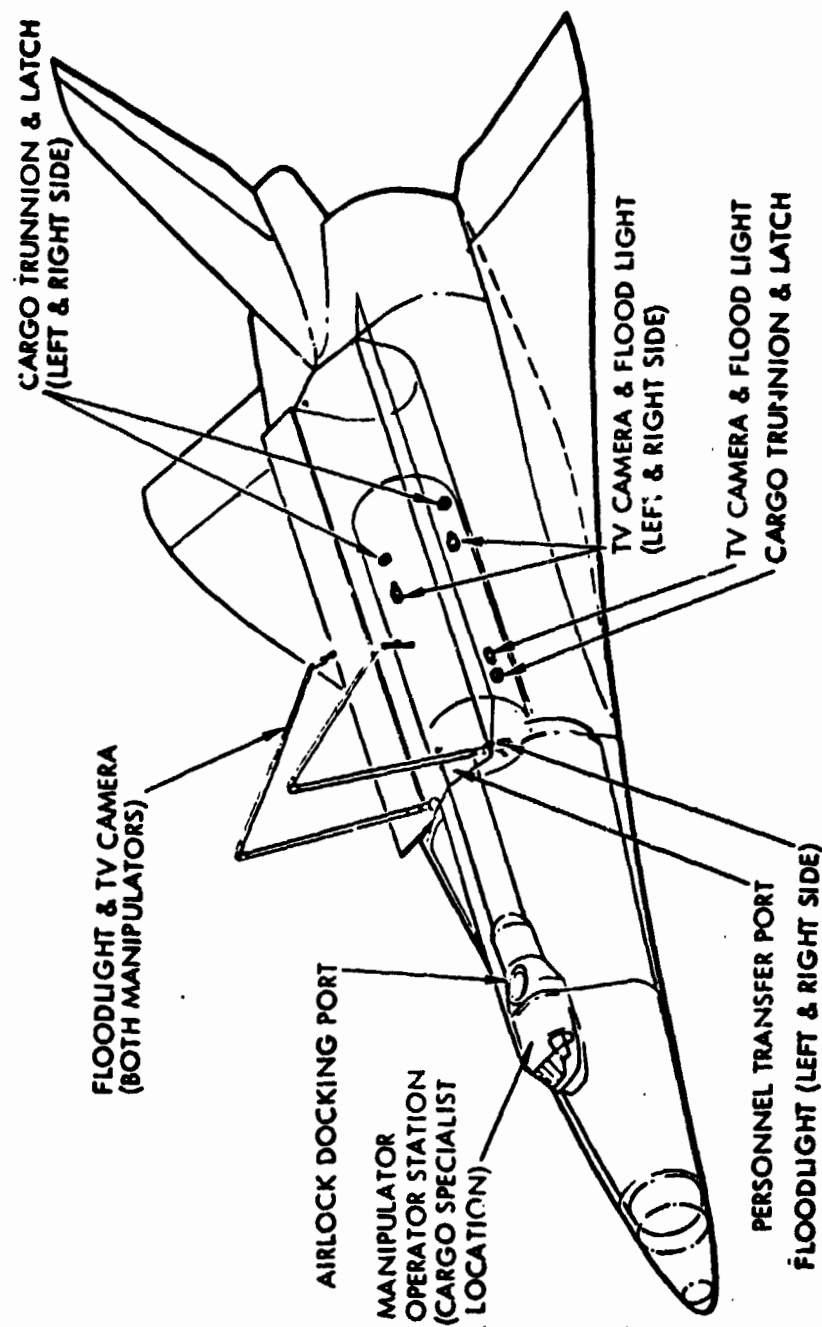


Figure 2-2. Typical Orbiter Showing Use of Manipulators





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- 1.3.002 Spillage or leakage of hazardous fluids or materials during mechanically assisted or remote transfer in pressurized modules.
- 1.3.003 Spillage or leakage of hazardous fluid or material during remote transfer in unpressurized area.
- 1.3.004 Failure of transfer mechanism and/or loss of control of cargo during transfer in pressurized or unpressurized areas.
- 1.3.005 A radioactive environment in a sortie module or Space Station, resulting from exposure or escape of radioactive material during transfer and handling of radioactive materials.

The numbers refer to the hazard/emergency analyses in Appendix D of this report, in which these were analyzed.

## 2.4 CONCLUSIONS AND RECOMMENDATIONS

The main outputs of this task are the safety requirements and guidelines which result from the hazard/emergency analyses. The hazard/emergency analyses are contained in Appendix D, and include the requirements and guidelines. The requirements and guidelines are also presented in Volumes IV and V of this report, arranged under the applicable vehicle (Shuttle orbiter, sortie module, upper stage vehicles, or Space Station).

Conclusions from this task, based on the hazard/emergency analyses, and supported by the analyses in Appendix A, are presented in the following paragraphs.

- The orbiter design is extremely sensitive to even small explosions in the cargo bay. Uncontained explosions equivalent to as little as 5 g (0.01 lb) of TNT may result in exceeding the structural design limit of the cargo bay structure ( $14 \text{ kN/m}^2$ , 2 psi) from blast overpressure. By comparison, a hand grenade is equivalent to 10 g (0.025 lb) of TNT and a fully loaded Centaur to approximately 2700 kg (6000 lb) of TNT.
- Any structural failure of a loaded upper stage vehicle while in the orbiter cargo bay which results in large leaks of both fuel and oxidizer will almost certainly be catastrophic to the orbiter.
- The energy content of even the smallest liquid propellant upper stage vehicle if released suddenly, is far more than can be tolerated by the orbiter. The vehicle accelerations caused by the reaction of the leaking fluids will ensure mixing, and an ignition source will almost certainly be present during the process of structural failure. A chemical reaction therefore can be expected, and this will probably propagate faster than the rate at which the fluids can disperse in space, even with the cargo bay doors open. Every effort must therefore be made to prevent structural failure of upper stage vehicles while in or near the orbiter. Remedial measures are not considered practical, and have not been recommended.
- If the leakage of large quantities of payload fluids into the orbiter cargo bay is considered credible during boost or while the orbiter is in orbit with the cargo bay doors closed, then additional venting of the cargo bay beyond that provided by the orbiter for normal venting may be required to avoid potential overpressurization of the cargo bay. This may need to be considered and provided for individually for each payload which contains large quantities of fluids.



- The chemical and physical behavior of gases, liquids, and cryogenic fluids is not well understood in the zero-g and zero or very low pressure environment encountered in space. An important area of uncertainty as to the potential effects of leaking fluids therefore exists, and the severity, or even the possibility, of hazards such as combustion, chemical reaction, corrosion, attachment of frozen gases to the structure, etc., cannot be properly evaluated at present. In the hazard/emergency analyses in this task, the worst-case assumption was made that effects which are theoretically possible, such as sustained combustion of leaking hypergolics, will indeed occur.
- Launching a Space Station or sortie modules pressurized at 1 atmosphere can present the orbiter with a considerable hazard. A typical station module of  $140 \text{ m}^3$  ( $5000 \text{ ft}^3$ ) volume has an explosive potential of 10 kg (22 lb) TNT equivalent. This arises because of the energy which could be released in the vacuum environment of space from the contained atmosphere. If this energy is instantaneously released, e.g., by structural failure of the module, the resulting blast and shrapnel would cause catastrophic damage to the orbiter. A rapid release of the contents of the module when the cargo bay doors are closed, without any blast effects, could still pressurize the cargo bay to about  $20 \text{ kN/m}^2$  (3 psi), or about 50 percent above its present design limit. Rapid release of the module contents when the cargo bay doors are open, or a slow enough release so that the orbiter cargo bay vent system can adequately relieve the pressure, would not result in damage.
- Many different fluids, of varying degrees of hazard and in varying quantities, are currently planned for transportation to and from space by the orbiter and for use in sortie modules and on the Space Station. While many general safety requirements and guidelines have been identified, and an adequate level of safety appears possible to both the personnel involved and the spacecraft, more specific safety features than defined in this study must await a more detailed definition of the spacecraft, payloads, and their planned operations than is currently available.
- Cargo handling in space presents some specific hazards associated with the zero-g environment and with the limited remedial and escape provisions available. In addition to normal safety features required on the ground, specific requirements and guidelines, such as tethering of heavy cargo at all times, double-containing hazardous cargo, and providing mechanical assist where propulsive forces are possible, have been identified.

The main recommendations from this task are contained in the safety requirements and guidelines developed during the hazard/emergency analyses. Specific top-level recommendations arising from these and from supporting analyses are described in the following paragraphs.

- The cargo bay doors on the orbiter should be opened as early as possible and closed as late as possible while in orbit when hazardous fluids or large quantities of propellants are carried in the orbiter cargo bay. This minimizes hazards from leakage, explosions, contamination, etc.
- The liquid contents of upper stage vehicles being returned to earth should be dumped to space before deorbiting the orbiter. The purpose is to avoid the possibility of an uncontrolled increase in internal upper stage vehicle pressure during reentry or on the ground, possibly from an unexpected heat leak. The acceptable level of residual liquids and gas before returning to earth should be such that an insulation failure, leakage, or a crash landing will not result in overpressurization, fire, or a similar accident.
- The capability should be provided for the orbiter to deorbit, reenter, and land with a fully loaded upper stage vehicle. This condition may arise from a failure to deploy the upper stage vehicle (perhaps because of lack of time following an abort situation) and failure to dump upper stage vehicle propellants. While such a combination of events may be quite improbable, the consequences could be catastrophic, and the condition should be designed for as being credible. It is not recommended that reduced factors of safety be considered for this situation, but the reentry and landing load criteria should be less severe than the normal design cases (e.g., 2σ conditions instead of 3σ) for this maximum weight condition, to avoid combining unrealistically severe worst-case design cases. The pilot in such situations will undoubtedly take extra care to avoid a hard landing.
- Upper stage vehicles must be man-compatible; i.e., man-rating safety criteria must be applied to systems and functions of the upper stage vehicle which could create a hazard to the orbiter while the upper stage vehicle is in or near the orbiter. These criteria, which are not currently defined, must be defined consistently for the Shuttle and for upper stage vehicles. One possibility is that a flight test of the upper stage vehicle be performed in the Shuttle using fluids which are physically similar to the propellants but which do not react chemically. For example,  $\text{LN}_2/\text{LH}_2$  may be used to simulate  $\text{LO}_2/\text{LH}_2$ . Such a flight test may be cost effective because it can also replace much of the ground qualification testing.



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- Because of the criticality to the orbiter of a failure of a pressurized sortie or Space Station module in the cargo bay while in space, two areas should be studied further:
  - Identify and eliminate failure modes which can cause major structural or other failures of pressurized sortie or Space Station modules during boost, on-orbit, and reentry phases.
  - Consider venting the modules to space while they are still in the cargo bay, to reduce the explosive potential. The necessary atmosphere can be taken up in a number of high-pressure tanks within the module. This has the effect of reducing the potential for damage, both by reducing the energy content per tank, and by reducing the pressure that can be generated in expanding the gas from a ruptured tank to the cargo bay volume.

## 2.5 RESIDUAL HAZARDS AND HAZARDS RESOLUTION

This section summarizes the hazards identified in Sections 2.1 to 2.3 and their resolution, and presents the resulting requirements for supporting research and technology.

### 2.5.1 Resolution of Identified Hazards

The disposition of the 25 hazards identified in Sections 2.1 to 2.3 is shown in Table 2-7. This shows the judgments of the investigation as to which hazards would be resolved by implementation of the recommended requirements and guidelines, and which are residual hazards; which of the residual hazards represent acceptable risks; and which require supporting research and technology (SRT) or must at present be considered unresolved safety issues. This hazards resolution has been performed in accordance with the procedures and definitions described in Appendix D.

### 2.5.2 Supporting Research and Technology Requirements

The supporting research and technology requirements resulting from the areas of uncertainty of this task are listed below (the main originating hazards/emergency are indicated in parenthesis):

- The behavior of pressurized cryogenics, gases, and liquid as they explode into vacuum or into a large evacuated container should be understood. The purpose would be to determine the explosive contents under different conditions and the damage that can result. The subject can initially be studied analytically and the key results verified by laboratory tests (1.1001, 1.2.005).
- Current and new techniques for designing, constructing, and operating tanks which can fail under pressure without producing shrapnel should be pursued (1.1001, 1.2.005).
- The use of strain measurements on pressurized tanks should be explored as a means of detecting impending failures on the tanks. This method has the potential advantage over conventional methods of monitoring temperatures and pressures of the contents that it can detect failures of the tank due to imperfections or weaknesses of the tank, as well as overpressurization (1.1001, 1.2.005).
- The potential for chemical combination of mutually reactive fluids and decomposition of monopropellants in a zero-g and low to zero-pressure environment should be investigated to evaluate



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Table 2-7. Hazards Resolution

Hazard No.	Hazard	Resolved	Residual	Acceptable Risk	SRT Requirements	Unresolved Safety Issue
1.1.001	Explosion/rupture of a pressurized container in an upper stage vehicle inside or near orbiter.		X		X	X
1.1.002	Combination of mutually reactive upper stage vehicle fluids leading to explosion or fire inside or near orbiter.		X		X	X
1.1.003	Inadvertent detonation of explosive charge on upper stage vehicle inside or near orbiter.	X				
1.1.004	Rapid decomposition of mono-propellants located in or leaking from the upper stage vehicle while inside or near orbiter.		X		X	
1.1.005	Uncontrolled combustion in active upper stage vehicle reaction control engines while near the orbiter.	X				
1.1.006	Leakage of corrosive fluids from upper stage vehicle tanks while inside the orbiter.		X		X	
1.1.007	Inadvertent start of an upper stage vehicle main or reaction control rocket engine while inside orbiter cargo bay.		X	X		
1.1.008	Inadvertent separation of an upper stage vehicle attach point while in the orbiter.		X	X		
1.1.009	Loss of attitude/translation control of upper stage vehicle upon release from orbiter.		X	X		
1.1.010	Hangup of upper stage vehicle during release from orbiter.	X				



Table 2-7. Hazards Resolution (Cont)

Hazard No.	Hazard	Resolved	Residual	Acceptable Risk	SRT Requirements	Unresolved Safety Issue
1.1.011	Rupture of common bulkhead tanks in upper stage vehicle while in or near orbiter.		X	X		
1.1.012	Loss of pressurization in pressure stabilized upper stage vehicle while in or near orbiter.		X	X		
1.1.013	Inability to dump propellants or pressurants in retrieved upper stage vehicle.	X				
1.1.014	Inability to dump upper stage vehicle propellants or pressurants during orbiter abort.	X				
1.1.015	Inability to close cargo bay doors after retrieval of upper stage vehicle because of interference with upper stage vehicle.		Y	X		
1.2.001	Exposure of the orbiter crew or passengers to a toxic environment released from a vessel in the payload containing a toxic fluid.		X	X		
1.2.002	A fire in the cargo bay resulting from release and ignition of a flammable fluid in an unpressurized payload.		X		X	
1.2.003	A fire in a pressurized payload in the cargo bay resulting from release and ignition of a flammable fluid.		X		X	
1.2.004	A corrosive environment in the orbiter cargo bay resulting from leakage or rupture of a payload vessel containing a corrosive fluid.		X		X	





Table 2-7. Hazards Resolution (Cont)

Hazard No.	Hazard	Resolved	Residual	Acceptable Risk	SRT Requirement	Unresolved Safety Issue
1.2.005	An explosion in the orbiter cargo bay of a potentially explosive payload vessel.		X		X	X
1.3.001	Spillage or leakage of hazardous fluid or material during manual transfer in pressurized modules.		X		X	
1.3.002	Spillage or leakage of hazardous fluids or materials during mechanically assisted or remote transfer in pressurized modules.		X		X	
1.2.003	Spillage or leakage of hazardous fluid or material during remote transfer in unpressurized area.		X	X		
1.3.004	Failure of transfer mechanism and/or loss of control of cargo during transfer in pressurized or unpressurized areas.	X				
1.3.005	A radioactive environment in a sortie module or space station, resulting from exposure or escape of radioactive material during transfer and handling of radioactive materials.		X	X		



how severe this hazard is. Some insight can be gained by theoretical studies, but full confidence would require small-scale laboratory tests in simulated or actual zero-g conditions. For monopropellant decomposition, the catalytic effect of different spacecraft materials should be investigated, as well. This would require valid pressures, temperatures, and concentrations, but the zero-g environment could probably be dispensed with except as a final verification (1.1.002 and 1.1.003).

- The behavior of corrosive fluids in zero g should be investigated to determine how serious the hazard of a leaking corrosive fluid could be, and to determine practical protection methods and remedial measures. Means for detecting the location of the corrosive fluid or of the corrosive action should also be investigated. This research should cover the range of pressures from full spacecraft pressures down to a vacuum. A particular point to be investigated should be the behavior of corrosive fluids which are frozen in a space environment and thaw out and become more active upon return to an earth environment (1.1006, 1.2.004).
- The flammability and chemical reactivity of spacecraft and payload materials under low pressure conditions representative of fluid leakage into the orbiter cargo bay should be investigated. The reactive gases should be fluids such as oxygen, hydrogen,  $N_2O_4$ , etc., which may be carried as propellants, cargo, or experiment fluids. The purpose would be (a) to understand the mechanics and dynamics of chemical reactions under zero-g and low-pressure conditions, and (b) to map areas of flammability and reactivity in terms of materials, pressures, temperatures, etc., for use as a guide in materials selection for forthcoming spacecraft (1.2.002).
- Means for detecting and suppressing fires in a zero-g pressurized environment should be investigated. This research should include understanding of ignition, heat transfer, and flame propagation; effects of air currents due to forced convection and low-g acceleration; and the convection effects of applying fire extinguishers to the fire. Both manned and unmanned situations should be considered. The investigation should consider a broad systems approach to the problem so as to lead to practical recommendations for space applications. Tests should be considered for the Skylab program to supplement the current proposed effort (1.2.003).
- Means should be developed for locating spilled hazardous fluids and materials in a zero-g manned environment and for neutralizing or collecting and disposing of these (1.3.001, 1.3.002).



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### 3.0 SHUTTLE TO SPACE STATION DOCKING OPTIONS

The Space Station Program Phase B Definition studies identified a concern as to the best way to effect docking between the shuttle orbiter and the space station. The safety aspects of bringing these two large and massive vehicles together were a prime consideration in the suggested docking methods. The safety issues became more acute when the modular space station was considered, because of the more frequent logistics resupply cycle of approximately once per month in which a module is exchanged, and because of the assembly operations, during which the space station is built-up a module at a time. This involves many docking operations, many of them with an unmanned vehicle during station build-up. Compared with the modular space station, the 10 m (33 ft) diameter station was to be supplied logistically on a 3 to 6 month cycle, and only in the initial docking was the station unmanned.

Among the systems that have been considered for docking are:

- The direct docking of the shuttle orbiter to the space station, as in the Apollo Program.
- The use of manipulators, on either the orbiter or station, to effect a more mechanically determinate docking maneuver, and at a much lower contact velocity than is practical with direct docking.
- An extendable soft-dock system which provides a larger distance between the docking vehicles at initial contact, and reduces the docking loads through the flexibility of the system.
- Free-flying and docking the individual space station or other modules between orbiter and station, so as to avoid the close proximity of orbiter and station. The station and orbiter station-keep at some distance from each other.

The purpose of this task was to identify, analyze and recommend resolution of the hazards involved in the suggested methods for docking the orbiter to the modular space station; and to make recommendations as to the preferred docking methods from the safety point of view.

Three kinds of operations were considered, as follows:

- Assembly of modular space station. This includes all phases from the assembly of the two initial unmanned modules, through build-up to a fully manned operational station.
- Normal resupply docking. This consists of the periodic routine logistics bringing up and docking of resupply or new modules to the station, and the undocking and return to earth of empty or otherwise unwanted modules.

- Emergency docking. A situation has occurred which makes the docking substantially different and introduces additional hazards.

The comparison of the various docking options was divided into two essentially uncoupled trade-offs. One trade-off was between three docking systems, and the other between two docking modes. The three docking systems are:

- Direct docking system
- Extendable tunnel docking system
- Manipulator docking system

The two docking modes are:

- Orbiter to station docking mode
- Free-flying module docking mode

The hazards identified in this task, and the resulting analyses, are applicable to any combination of docking vehicles which use the docking systems and modes considered here, providing at least one of the vehicles is manned. The comparisons and evaluations of the systems and modes, and the conclusions and recommendations reached, however, cannot be applied to all such vehicle combinations without careful re-evaluation. The reason is that the effects and criticality of the hazards may differ according to the configuration, size, mass, control systems, and other features of the vehicles. The further these features vary from the orbiter, space station and individual free-flying modules considered here, the less the confidence that can be placed on the applicability of the results and conclusions.

Further differences which may invalidate the results of this task arise when additional hazards exist because of the nature of the vehicles. For example, when one of the docking vehicles is a propulsion stage (e.g., a tug) or contains large quantities of propellants (e.g., a propellant depot), hazards associated with propellant slosh, leaks, etc., must be additionally considered. Forces due to propellant slosh during docking, for example, negligible on the orbiter (while in orbit), the sortie modules and the space station compared to the docking loads, and have not therefore been considered to produce any hazard during docking. Another example is a reusable nuclear shuttle, which poses nuclear radiation hazards. For such vehicles, the conclusions of this task must be re-assessed.

The analyses are presented as follows:

Section 3.1 The docking systems and modes considered and described

Section 3.2 The potential hazards associated with docking are identified

Section 3.3 The docking systems are compared and evaluated

Section 3.4 The docking modes are compared and evaluated

Section 3.5 Emergency docking is considered

Section 3.6 The conclusions and recommendations of the task are presented

Section 3.7 The identified hazards are resolved according to procedures described earlier.

Supporting analyses are presented in Appendix B, and hazard/emergency analyses in Appendix D. The resulting requirements and guidelines are contained in Volumes IV and V.

### 3.1 BASELINE MODEL

The baseline model described in this section illustrates the features of the three docking systems, the two docking modes, and the assembly, normal resupply docking and emergency docking operations which were considered during this task. This baseline model specifically describes features pertinent to this task. To place the docking operations in the context of the wider perspective of the space program being considered, the reader is referred to the baseline model in Section 1.4.

While the descriptions in this baseline model are fairly definite, a conscious attempt has been made to describe those features which are significant in identifying the differences between the various docking systems and modes, particularly as they affect the safety issues. A section has been added at the end of each sub-section which describes possible variations which would not affect the safety trade-offs and conclusions. Such variations should be considered as typical only, and not exhaustive.

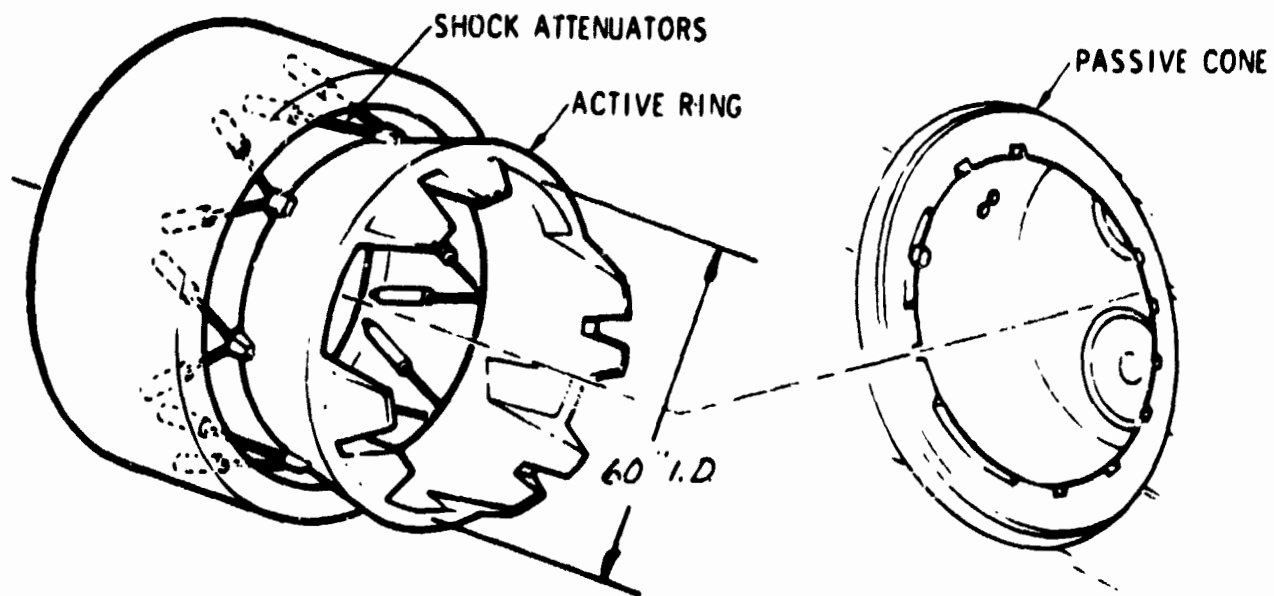
#### 3.1.1 Direct Docking System

The direct docking system involves the approach of the two docking vehicles right up to each other so that the integrally attached docking mechanisms can make contact for initial capture. The system is characterized by the use of the propulsive capability of one of the mating vehicles to effect final closure and docking contact and a relatively short and stiff impact attenuation stroke of the docking system. Typically, this stroke is approximately 0.3 m (10 in) or less.

The NR and MDAC docking system concepts developed in the Space Station Phase B studies are direct docking systems. These are shown in Figure 3.1-1. Both systems are similar in that they are structurally integral with the docking vehicles. They employ a docking ring or frame with vehicle alignment features, docking interface seals, capture latches, impact alternators, equipment for retracting the mated vehicles after capture, and capability for rigidizing the docking interface. Although the attenuation stroke capability may be varied by the design, both of these use the short stroke characteristic of direct docking systems.

The use of the direct docking system is illustrated in Figure 3.1-2 for the orbiter to station docking. This may occur via an intermediate payload to the modular space station, as shown in the top illustration in which the orbiter is delivering a module to the station; or directly at the orbiter docking interface, as in the lower illustration, in which the orbiter is retrieving a module for return to earth. Direct docking may also occur when a free-flying module docks either to a station or to an orbiter.

The direct docking system requires the dissipation of relatively large energy levels because of the coarse velocity control expected for propulsive maneuvers of the large masses involved.

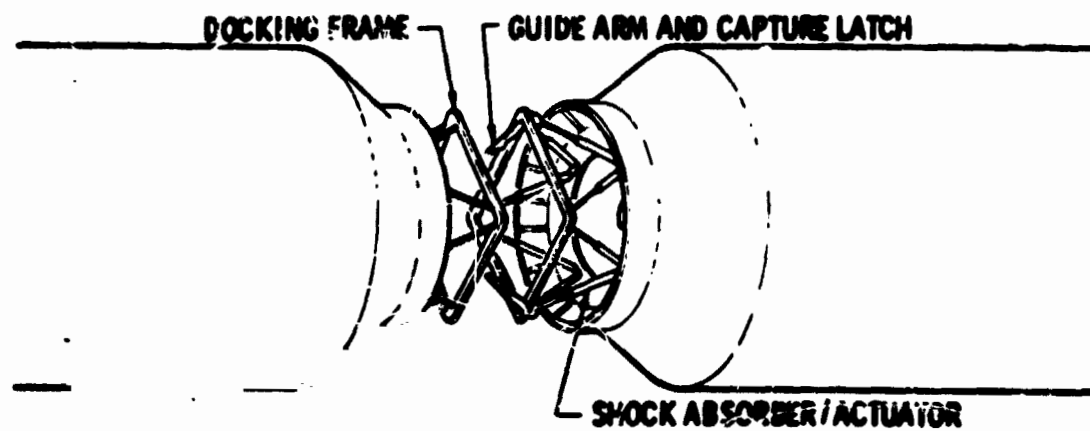


#### Active Ring/Cone

- . Docking Ring
- . Seals
- . Docking Latches
- . Cone
- . Capture Latches
- . Attenuator/Retractor
- . Latch Notches

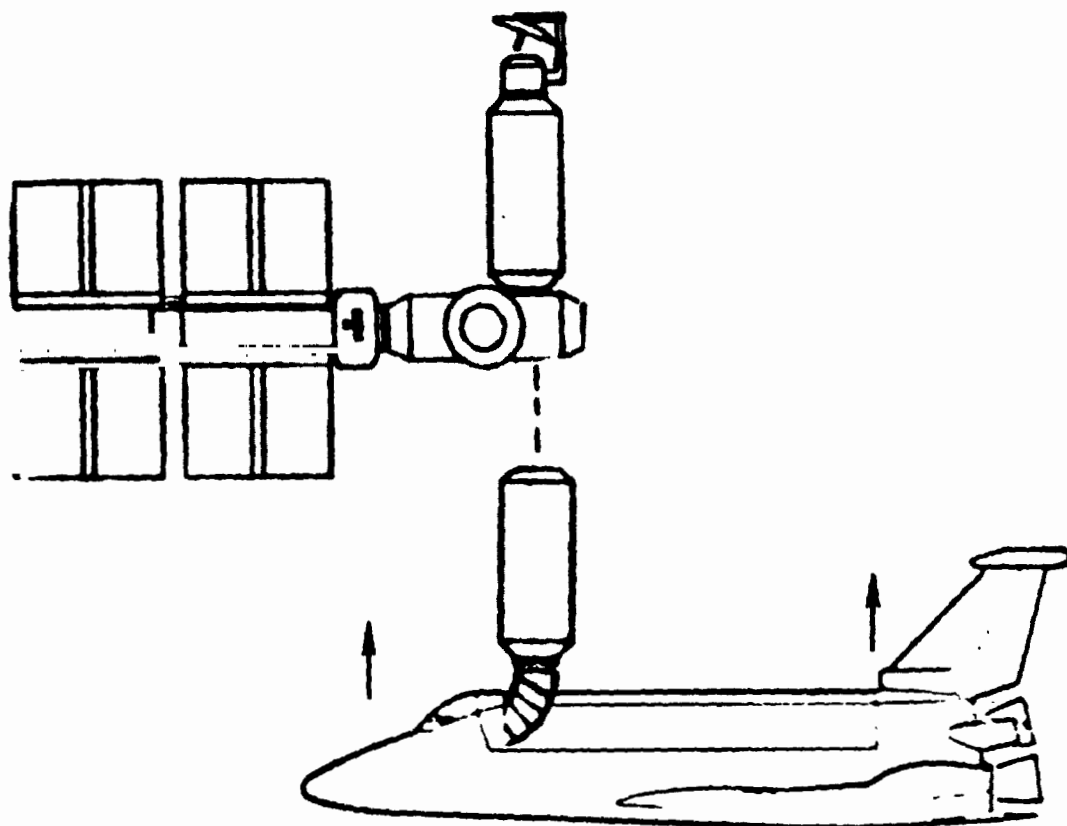
#### Passive Ring

#### NR CONCEPT

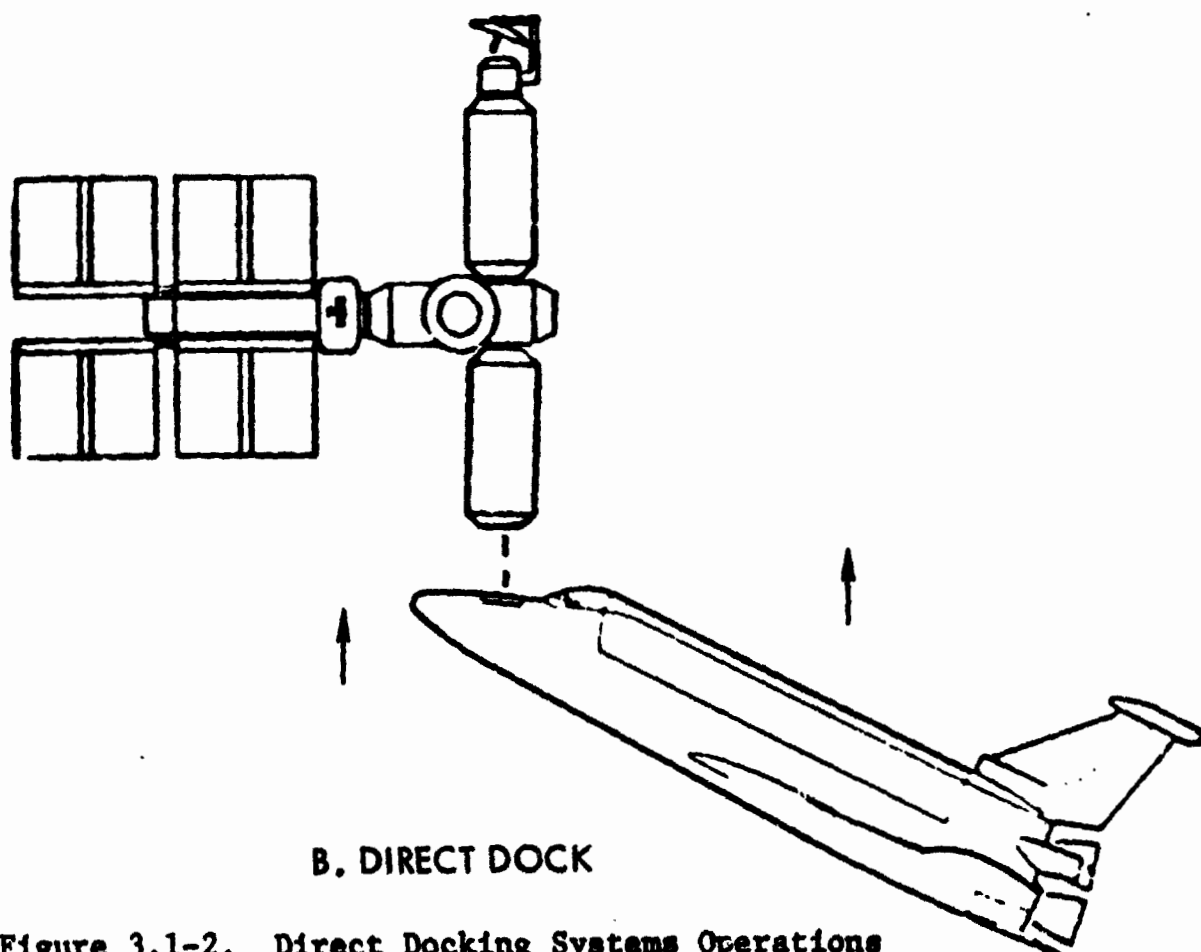


#### MDAC CONCEPT

Figure 3.1-1. Direct Docking System Concepts



A. DIRECT DOCK VIA INTERMEDIATE MODULE



B. DIRECT DOCK

Figure 3.1-2. Direct Docking Systems Operations





### 3.1.2 Extendable Tunnel Docking System

The extendable tunnel docking system uses an extension mechanism of some kind so as to extend the docking mechanism on one of the two docking vehicles some distance from the vehicle before effecting initial contact and capture, and is then retracted to draw the two vehicles together for rigidizing. The distinguishing features of the extendable tunnel docking system are that it provides a long separation distance of the two vehicles at the instant of first contact, it provides stability after capture and during draw down and affords a long stroke, low stiffness attenuation capability. Although the system is called an extendable tunnel system because the particular concept analyzed uses an inflatable extendable tunnel, the system may use other means for providing the extension and stiffness. Mechanical linkages, and hydraulic, electrical or mechanical actuation could be used. The important features are the relatively long extension, and adequate bending and torsional stiffness.

One extendable tunnel docking system concept adapted from a concept considered for the Apollo, is shown in Figure 3.1-3. It employs a docking port attached to one end of an accordion-like bellows tube, extendable to approximately 3 m (10 ft) in length, the other end of which is attached to one of the docking vehicles. The stroke attenuation capability is approximately 10 times greater than for direct docking systems. The tunnel consists of a double walled bellows which is fully retractable to a locked position for stowage during non-docking orbital operations. Deployment of the tunnel for docking operations consists of extending the bellows from its retracted position by pressurizing the volume contained between the double walls at a relatively low pressure. Docking is performed with the tunnel fully deployed. The impact attenuation capability is obtained from release of gas through restrictive orifices during compression of the tunnel. Reel mechanisms or equivalent devices retract the tunnel during the rigidizing procedure after capture. Pressurization of the tunnel after rigidizing and during docked operations is not necessary because the tunnel is outside the docking seals.

A version of this docking system was designed at NR for the Apollo in 1963, and tested as part of the final evaluation and selection of the docking system. It was one of four extendable systems designed and tested for this purpose. Tests in two-dimensional simulated docking of this system, which had a 75 cm (30 inch) diameter tunnel, and extended to approximately 3.7 m (12 ft), showed that it was feasible, and had no major problems. The other three extendable systems consisted of a small (10 cm, 4 inch) inflatable tunnel, and two extendable stem devices; these three systems generally encountered control problems due to insufficient stiffness, and required use of the reaction control system to assist in damping the lateral motions.

These four extendable systems were compared with three direct docking systems. The probe and drogue system selected for the Apollo was one of these three direct docking systems.

The extendable tunnel system can be used in two different methods. In the first method, illustrated in Figure 3.1-4, the docking system is first fully extended, and initial contact and capture are effected by propulsive maneuvering of the whole vehicle. In the second method, illustrated in Figure 3.1-5, the two vehicles station-keep at a relatively close distance

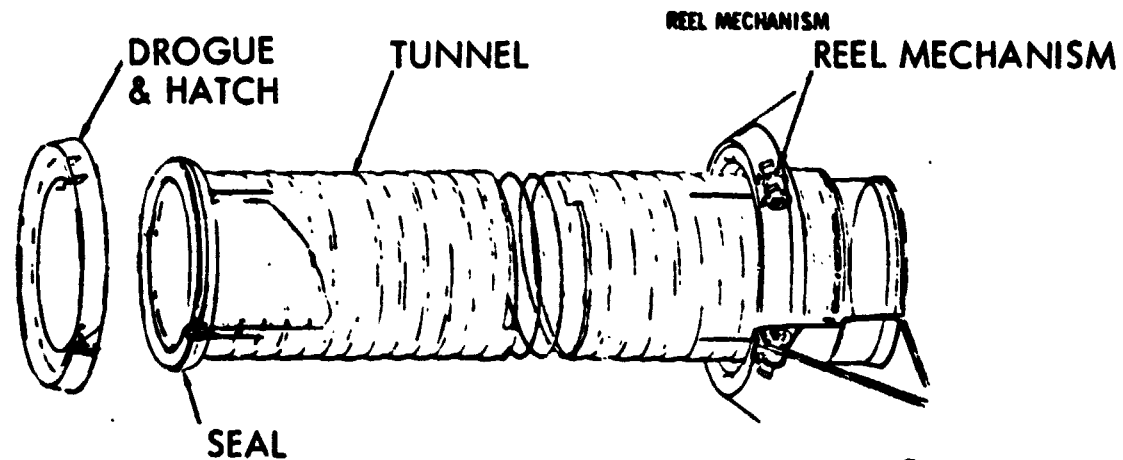


Figure 3.1-3. Extendable Tunnel Docking System Concept

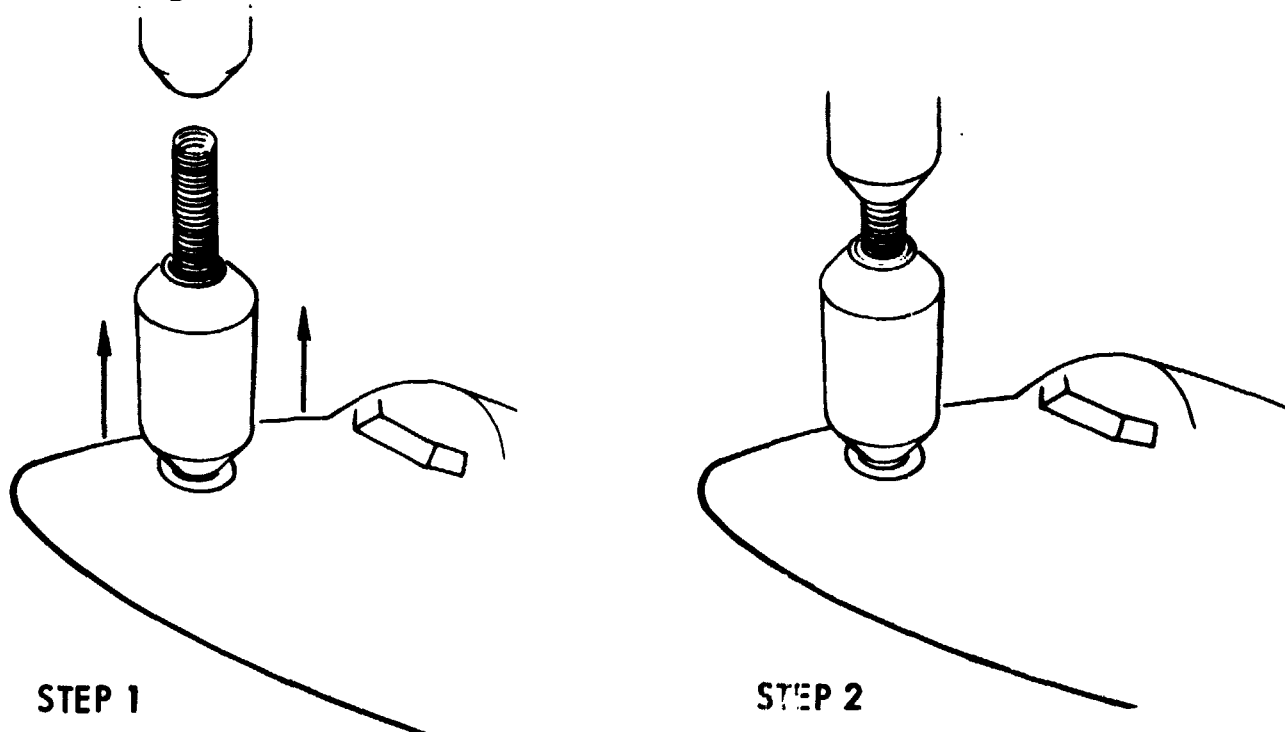


Figure 3.1-4. Extendable Tunnel Docking System, Docking Vehicle Active

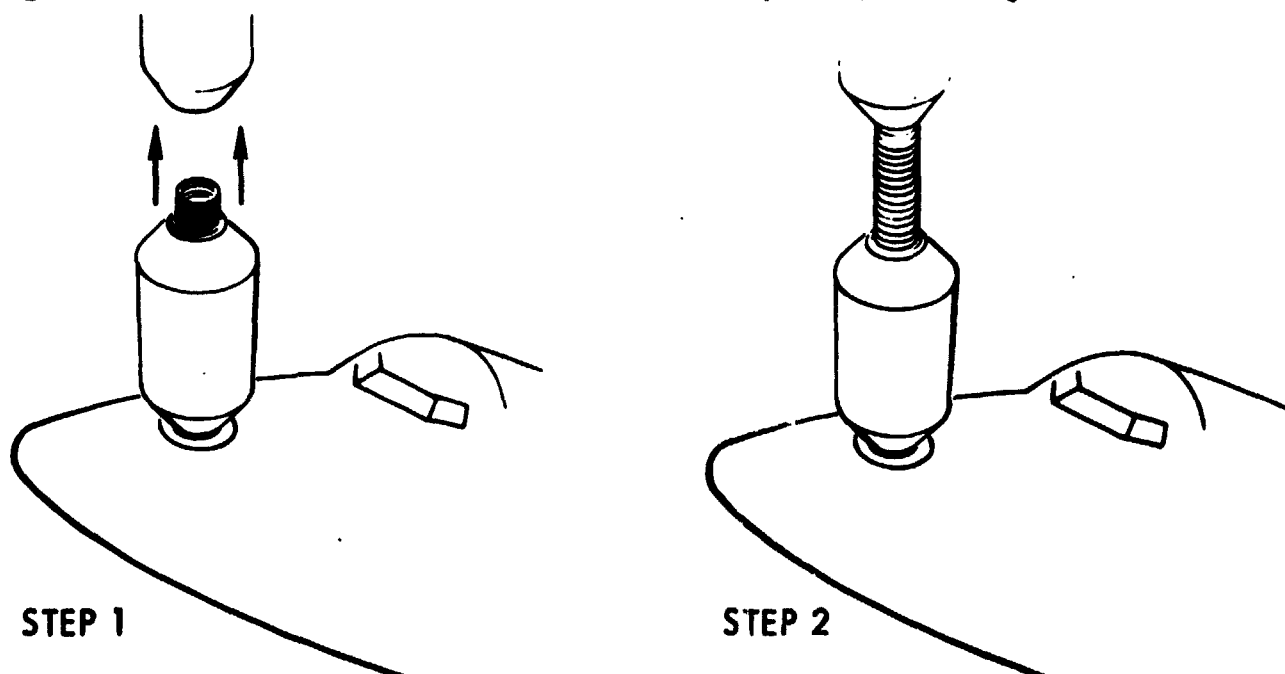


Figure 3.1-5. Extendable Tunnel Docking System - Docking Vehicle Station-Keeping, Docking System Active



before the docking system is extended, and initial contact and capture are effected by extending the docking system relative to the stationary vehicle. The first method requires the docking system to absorb all of the kinetic energy of the moving vehicles, whereas in the second method this energy has been taken out by the propulsion system, and the docking system need only absorb the energy of the moving docking system itself. The first method, in which the system is first extended and the whole vehicle moves to dock, was generally considered in the analyses that follow, as this poses the more stringent safety issues. The results of the analyses, and the conclusions, are applicable, however, whichever method is used.

### 3.1.3 Manipulator Docking System

The manipulator docking system is characterized by the use of a manipulator on one of the docking vehicles to effect capture of the other one and to bring the two vehicles together for docking, latching and rigidizing. The particular features which make the manipulator docking system different from the other systems are:

- (a) The two docking vehicles station keep at some stand-off distance before docking.
- (b) A control system is used to deploy the manipulator and effect initial contact and capture of the other vehicle.
- (c) The manipulator is controlled to bring the two vehicles together at a low controlled velocity to effect alignment and latching of the docking hatches. The energy attenuation requirements are low.
- (d) The manipulator has many degrees of freedom in articulation, so that it can maneuver the two vehicles through relatively complex positions.

It should be noted that the first three items above are also characteristic of the extendable tunnel docking system when used in the method with the vehicles station keeping and the docking system effecting capture and closure. It is only the last feature, the complexity of the manipulator, that distinguishes the manipulator system from that particular version of the extendable tunnel system.

A typical manipulator configuration is shown in Figure 3.1-6. This consists of a multi-jointed mechanical arm approximating 20 m (60 ft) in length attached to one of the docking vehicles. It has a shoulder, elbow and wrist, whose functions and articulation correspond with the same parts of a human arm. A variety of specialized tools can be attached to the wrist to perform the specific functions of each mission.

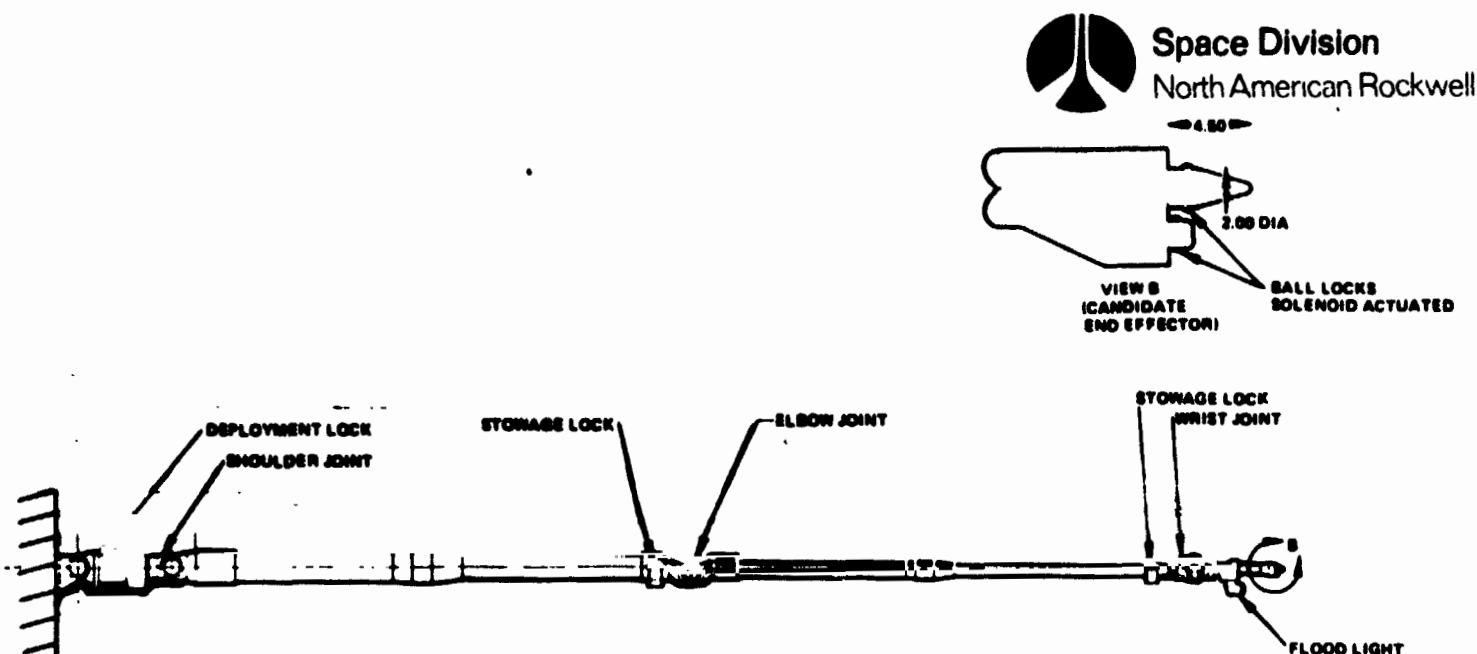


Figure 3.1-6. Typical Manipulator Concept

One concept for integrating the manipulator into the orbiter, resulting from NR Phase B studies, is shown in Figure 3.1-7. Features include two manipulators with peripheral illumination, visual (video) and operating aids, and a manipulator operator station in the orbiter for manually controlling or observing automatic control of the manipulator. The docking functions have generally been conceived as being performed by either manipulator on its own, the second one providing a backup function. The manipulators are normally stowed along the length of the cargo bay, and are protected from the boost and re-entry environments by the cargo bay doors.

For practical nomenclature purposes, the manipulator or manipulators are assumed to be on the shuttle orbiter in the remainder of this task. The results and conclusions apply whatever vehicle the manipulators are on, however; in which case wherever the term "orbiter" is used, this should be replaced by "the vehicle with the manipulators."

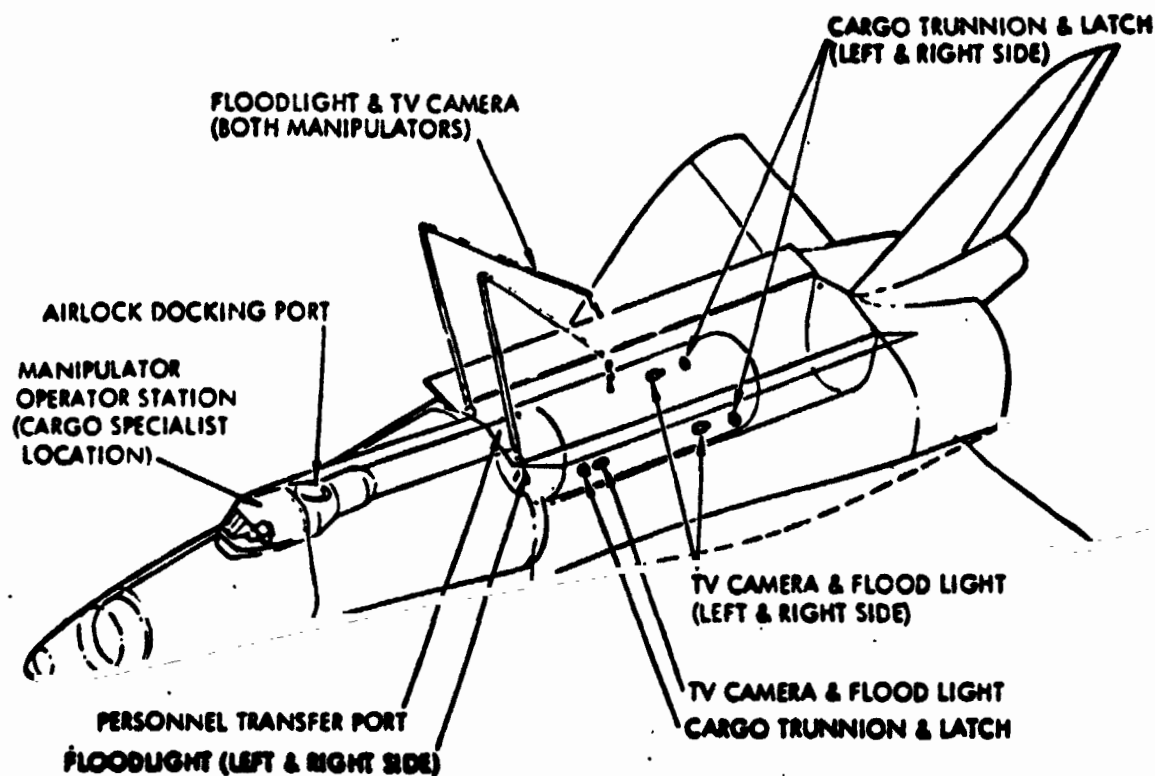


Figure 3.1-7. NR Phase B Orbiter with Manipulators

Three basic methods can be used for manipulator docking. These are, respectively:

- o Station keeping method
- o Dual dock method
- o Dual manipulator method

and are illustrated in Figure 3.1-8.

The station keeping method requires that the orbiter and the target vehicle station keep in an attitude hold mode within reach distance of the manipulator. While maintaining the position, the orbiter uses the manipulator to remove the payload module from the cargo bay and maneuvers it to effect docking with the target vehicle. Removal of a module from the target vehicle would be similarly accomplished.

The dual dock method requires manipulator capture of the target vehicle. In this technique, the orbiter and target vehicle station keep within reach distance of the manipulator, which reaches out, captures the target vehicle, and retracts it to a docking position on an orbiter docking port. After this operation is accomplished, the orbiter employs the manipulator to remove the payload module from the cargo bay and attach it to the selected docking port on the target vehicle. Removal of a module from the target vehicle requires, as before, capture and docking of the target vehicle prior to module removal by the manipulator.

The dual manipulator method combines features from the other two methods, and requires two manipulators, as the name implies. One manipulator is used to capture the target vehicle, as in the dual dock method. Instead of docking the target vehicle to the orbiter, however, the first manipulator is used to hold the target vehicle in a fixed position. The second manipulator is now used as in the station keeping method to deploy and dock the module to the target vehicle. The target vehicle is attached to the orbiter, but because of the flexibility of the manipulator, more loosely than in the dual dock method.

In all three of these methods the undocking is performed in the reverse order of the docking.

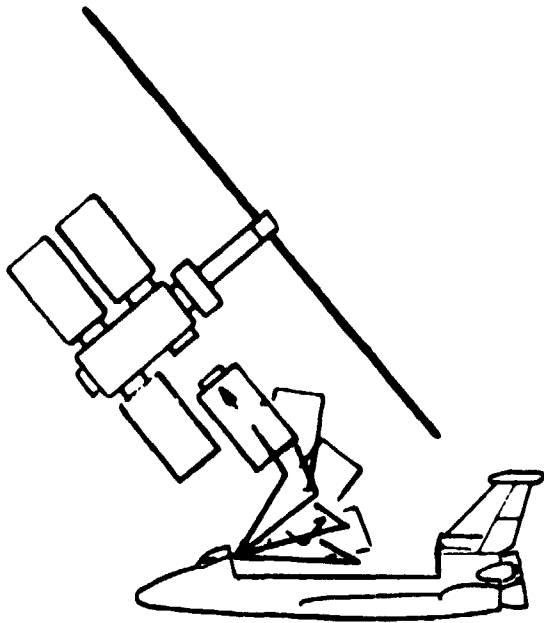
All three methods have been considered in the study task.

#### 3.1.4 Orbiter-to-Station Docking Mode

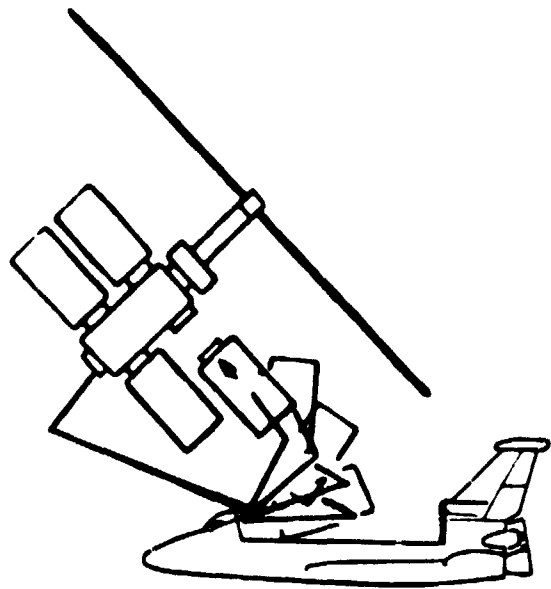
Two different modes of docking are possible with each of the docking systems described earlier. These are the orbiter to station docking mode and the free-flying module mode.



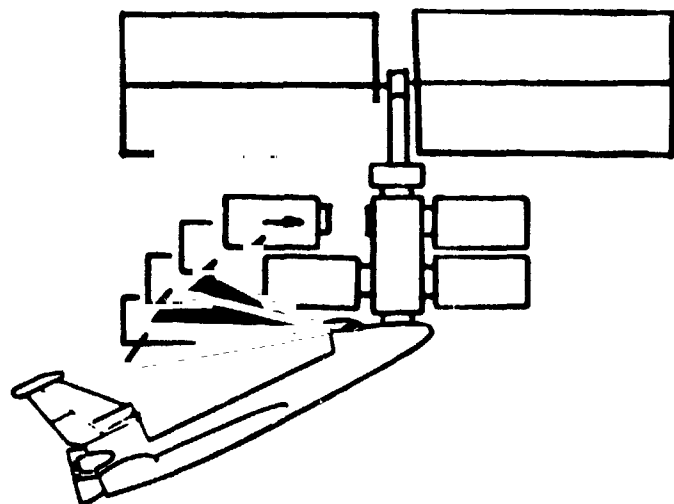
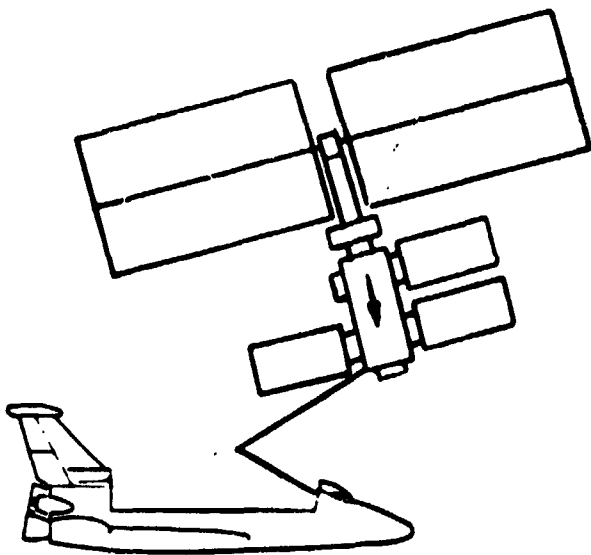
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STATIONKEEPING DOCKING METHOD



DUAL MANIPULATOR DOCKING  
METHOD



DUAL DOCK DOCKING METHOD

Figure 3.1-8. Stationkeeping, Dual Manipulator and Dual Dock Methods



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The orbiter to station docking mode is characterized by the docking of the orbiter to the station as illustrated in Figure 3.1-9 or vice versa. This means that the two vehicles approach each other to within the distance required by the particular docking system used, i.e., within 0.3 to 20 m (1 to 60 ft). The orbiter may have a module deployed so that the docking interface is between the attached module and the space station (Figure 3.1-2A), or the docking may be directly to the orbiter docking interface (Figure 3.1-2B). In either case, this mode results in the attachment through the docking port interface of two large masses, namely the orbiter and station, which are each of the order of 90,000 kg (200,000 lb).

### 3.1.5 Free-Flying Module Docking Mode

The free-flying module docking mode, illustrated in Figure 3.1-10 uses a free-flying module to fly between and dock to the orbiter and station. In this way the orbiter and station can stand off from each other in station keeping modes at a relatively large distance, which may in practice be 150m to 1.5km (500 ft to 1 mi). The free-flying module may be manned or unmanned. All dockings occur between an individual module, typically of 9,000 kg (20,000 lb) mass, and the station or orbiter. Docking impact energies are therefore only 20 per cent or so of those involved in the orbiter to station docking mode (at the same velocity).

Each free-flying module involved in this mode requires attitude control, propulsion, guidance and communications capability. This may be achieved in three distinct ways:

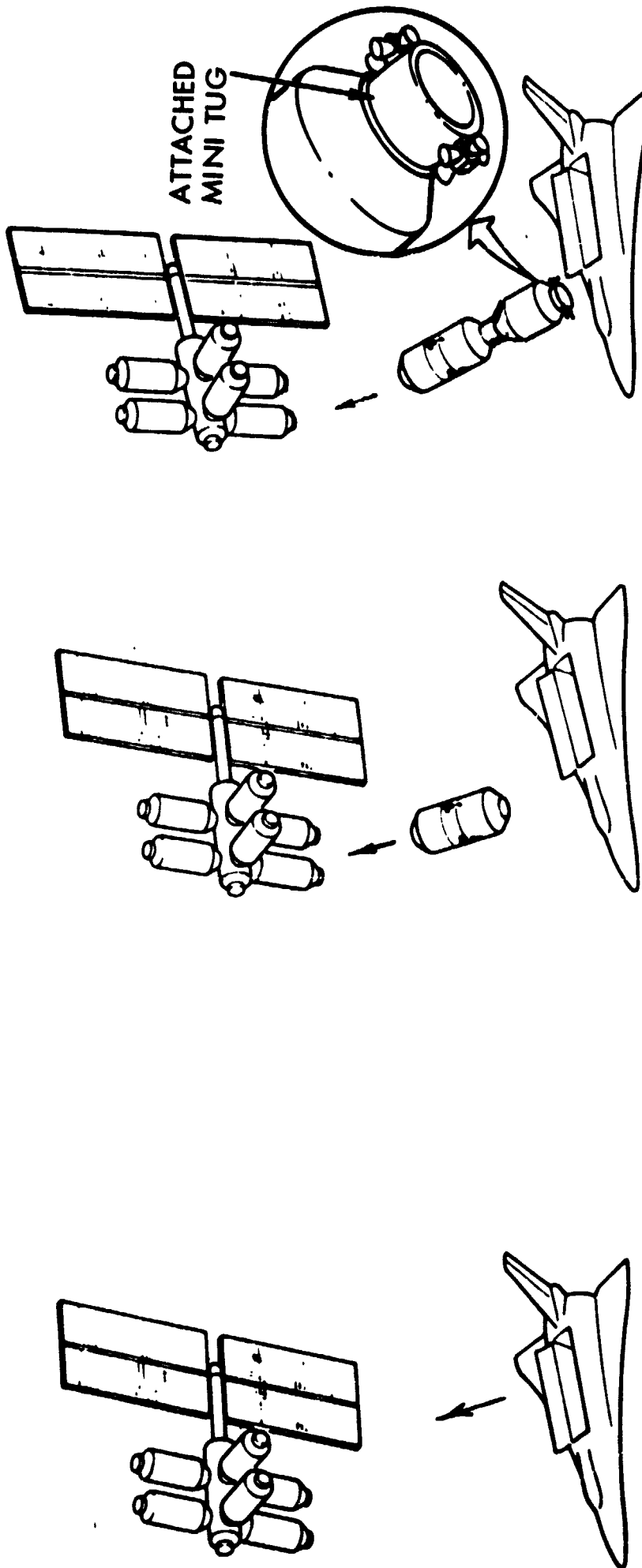
- Integral systems module
- Space-based mini-tug
- Ground-based mini-tug

In the integral systems module (Figure 3.1-10A), all the guidance, control and other functions are provided by systems on board each of the involved modules. If the modules are to be manned during the free-flying maneuver, life support systems must also be included.

In the two mini-tug concepts (Figure 3.1-10B), these functions are provided in a separate mini-tug vehicle, leaving the free-flying modules free of these additional system requirements. The mini-tug is envisioned as a relatively small module, since the propulsion needs are small. In addition to the functions mentioned earlier, it must be able to dock and undock with the free-flying modules, station and orbiter and must also be able to free-fly without an attached module. The advantage of the mini-tug is that a single mini-tug can provide the functions for all the free-flying modules, whereas in the integral systems module concept, each module must contain the various systems.



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A. INTEGRAL SYSTEMS MODULE B. MINI-TUG CONCEPT (GROUND  
BASED AND SPACE BASED)  
CONCEPT

Figure 3.1-9. Orbiter to Station  
Docking Mode

Figure 3.1-10. Free-Flying Module Docking Mode





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In the ground based mini-tug concept, the mini-tug is attached to the module to be delivered before launch. Orbital operations for docking are identical to those of the integral systems module concept. After docking to the space station, however, the mini-tug is undocked from the delivered module and flown back to the orbiter for return to earth and preparations for the next flight, or is used to return another module from the station to the orbiter for return to earth.

In the space based mini-tug concept, the mini-tug is based at the station. It flies to the orbiter, docks to the payload module and flies it to the station. Modules are transferred from the station to the orbiter in the reverse order.

### 3.1.6 Assembly and Normal Resupply Docking Operations

Docking operations are common to the station assembly and to normal resupply operations. During the assembly, docking is required to assemble modular space station elements into a modular space station which is capable of supporting a crew and the routine conduct of experiments. During the normal resupply phases, docking is required to support cargo and experiments resupply, crew rotation, and waste disposal.

The most significant considerations for docking, as related to the mission phases, is that docking during the assembly of the station involves (1) dockings with an unmanned station and (2) continually changing mass characteristics of the station. Since these considerations do not result in operational differences between assembly and resupply dockings, they are treated as one set of operations for this task.

The primary modular space station concepts being considered at the current time by NR and MDAC for a 6-man space station are shown in Figures 1-8 and 1-9. These figures include the buildup sequence and the capability within each module after buildup.

The NR station consists of nine modules requiring a like number of orbiter flights and eight dockings. The MDAC station requires four orbiter flights and three dockings, as shown, to achieve a 2-man crew initial continuous manning capability. Two more logistics module flights and two Research and Application Module (RAM) flights are required to provide 6-man continuous manning with initial station experimentation capability consistent with the NR station.

Both stations are capable, after buildup to the initial station, of supporting a crew of six and can expand to growth station with a crew of up to 12 and increased experimental capability with the addition of more modules.

### 3.1.7 Emergency Docking

Analysis of the docking systems included consideration of emergency docking to identify hazards and considerations in tradeoff evaluations.

Identification and evaluation of potential emergencies has shown that, so far as docking is concerned, emergency docking is characterized by one of the following two situations:

- (1) A time critical situation on the orbiter, free-flying module, or station, in which a docking is required to save or prevent injury to personnel or damage to the vehicles, or otherwise prevent a hazardous or dangerous situation from reaching capastrophic proportions.

Examples of time critical situations are fire, fumes, impending explosion, leakage, atmospheric depressurization, failure of life support, power failure and injured personnel.

- (2) Docking to a vehicle which has lost or experienced degradation of a critical docking function.

Examples are attitude control failure and docking to a slowly tumbling vehicle.

Both of these emergency docking operations have been considered in the subsequent analyses.

### 3.2 HAZARDS IDENTIFICATION

This section described the identification of potential hazards associated with the docking systems and modes described in the previous section (Section 3.1, Baseline Model).

The general method used to identify these hazards consists of setting out the functions which have to be performed, and then considering what hazards may arise in each function from equipment failures, operational errors, unexpected environments and major malfunctions or accidents. The section, therefore, starts with an analysis of the docking functions, and continues with a methodical identification of hazards peculiar to the various docking systems and modes.

The hazards identified were reviewed by a number of NR/SD pilots and NASA astronauts for credibility and completeness. Their comments have been incorporated in the analysis that follows.

#### 3.2.1 Functional Analysis of Docking Systems

Top-level functions required by the docking systems for docking of two spacecraft were defined and are listed in Table 3-1. These are general, and are applicable to any set of vehicles, and to all the docking systems and docking modes considered. Individual differences between docking systems and modes are identified and compared later. The top-level functions have been divided for convenience into four different maneuver phases:

- Pre-contact
- Contact
- Post-contact
- Undocking

A comparison of the three docking systems being considered (direct dock, extendable tunnel and manipulator) shows that substantially different means are used in the three systems to meet the functional requirements. These differences are high-lighted in Table 3-2, in which the design features used for each function are identified for the three docking systems. Only those functions in which inherent differences exist between the systems are shown. Alternate means for performing a function within a given system are also shown.

As can be seen from the table, the primary differences in the systems are related to the final closure function in the pre-contact phase, the energy attenuation function in the contact phase, and the capture and draw-down functions in the post-contact phase. The two methods identified for the extendable tunnel system (Section 3.1.2) differ only in the method of energy attenuation. The three methods of using the manipulator docking system described in Section 3.1.3 and shown in Figure 3.1-8 differ considerably in their operations when examined one level below the top-level functions of Table 3-1. These are compared in Table 3-3, using the six key operations of attach, release, extend, retract, dock, and undock.



Table 3-1. Top-Level Functions Required for Docking

Pre-Contact Flight Phase

1. Acquisition - One vehicle must locate the other either visually or electronically.
2. Gross Orientation - One vehicle must maintain attitude hold, while the other translates and rotates into alignment. The vehicle maintaining attitude hold will be called the "passive" vehicle.
3. Station Keeping - The active vehicle must station keep with the passive vehicle for inspection of the docking port condition. Active vehicle attitude hold is required.
4. Deploy Docking System - The active vehicle must deploy or arm the active portion of the docking system.
5. Fine Orientation - The active vehicle must fine align the active docking system with respect to the passive vehicle docking port in both translation and rotation.
6. Final Closure - The active vehicle docking interface must be maneuvered to contact the passive vehicle docking port. Lateral drift and residual attitude misalignment must be corrected during axial closure.

Contact Phase

1. Energy Attenuation - The active vehicle docking system must absorb the energy of relative motion between the two vehicles.

Post-Contact Phase

1. Capture - The active vehicle mating system must provide connection to the passive vehicle.
2. Attitude Alignment - Residual attitude misalignments between the vehicles must be corrected either by active vehicle maneuvering or by the capture mechanism prior to seating the mating interfaces. If the capture mechanism provides attitude alignment, the active vehicle must be placed in the free mode (i.e., no attitude hold). The passive vehicle remains in the attitude hold mode. Failure to inhibit attitude hold on one of the vehicles will cause both control systems to fight to hold their respective misaligned attitudes.

Table 3-1. Top-Level Functions Required for Docking (Cont.)

Post-Contact Phase (Continued)

3. Draw Down - The docking interfaces must be drawn together to remove residual attenuation stroke and seat the interfaces.
4. Rigidizing - The docking interfaces must be structurally connected either automatically or manually to provide the required intervehicular stiffness for combined vehicle maneuvering. This function also can seat pressure seals if intervehicular pressurization is required.

Undocking Phase

1. Unrigidize - The docking interfaces must be structurally disconnected to provide a flexible coupling for independent vehicle maneuvering. This function can also unseat pressure seals and be combined with the separation function.
2. Separate - The docking interfaces must be physically separated. Energy stored in the docking system may be used to provide or augment separation forces.
3. Recycle Docking System - The docking interface must be left in a condition to dock again. The rigidizing latches shall extend the attenuators to the unstroked position, the capture latches shall be unlocked and recycled, and the docking systems stored.



Table 3-2. Comparison of Design Features of Docking Systems by Function

<u>Function</u>	<u>DOCKING SYSTEM</u>		
	<u>Direct Dock</u>	<u>Extendable Tunnel</u>	<u>Manipulator</u>
<u>Pre-Contact Phase:</u>			
Deploy Docking System	Rotatable docking mechanism and/or direct dock system	Extendable tunnel	Manipulator
Final Closure	Propulsive maneuver	Propulsive maneuver or tunnel extension	Manipulator extension
<u>Contact Phase:</u>			
Energy Attenuation	Shock absorbers	Tunnel air compression	Manipulator joint torque
<u>Post Contact Phase:</u>			
Capture	Capture mechanism	Capture mechanism	Manipulator
Attitude Alignment	Capture mechanism or propulsive maneuver	Tunnel or propulsive maneuver	Manipulator
Draw Down	Capture mechanism retraction	Tunnel retraction	Manipulator retraction
Rigidizing	Latching (or equivalent) mechanism	Latching (or equivalent) mechanism	Latching (or equivalent) mechanism
<u>Undocking Phase:</u>			
Unrigidize	Latching (or equivalent) mechanism release	Latching (or equivalent) mechanism release	Latching (or equivalent) mechanism release
Separate	Stored docking system energy and/or propulsive maneuver	Stored docking system energy and/or tunnel extension and/or propulsive maneuver	Stored docking system energy and/or manipulator extension and/or propulsive maneuver
Recycle Docking System	Recycle latches and attenuators	Recycle latches and attenuators, stow tunnel	Recycle latches and attenuators, stow manipulator

Table 3-3. Comparison of Operations for Manipulator Docking Methods

Operation	METHOD		
	Station Keeping	Dual Dock	Dual Manipulator (1) = Manip #1 (2) = Manip #2
o Attach manipulator to module in cargo bay	X		
o Extend manipulator	X	X	X(1)
o Attach manipulator to station		X	X(1)
o Attach manipulator to module in cargo bay			X(2)
o Extend manipulator			X(2)
o Dock module to station	X		X(2)
o Release manipulator from module	X		X(2)
o Retract manipulator	X	X	X(2)
o Dock station to orbiter		X	
o Release manipulator from station		X	X(1)
o Attach manipulator to module in cargo bay		X	
o Extended manipulator		X	
o Dock module to station		X	
o Release manipulator from module		X	
o Attach manipulator to station		X	
o Undock station from orbiter		X	
o Extend manipulator		X	
o Release manipulator from station		X	
o Retract manipulator		X	X(1)



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An appreciable difference is seen in the number of operations required by each of the three methods. The station keeping method uses only 5 operations, the dual dock 14, and the dual manipulator 9 (4 by one manipulator and 5 by the other).

The functions shown in Table 3-3 are for the orbiter docking a module to the station. The operations required for undocking a module from the station are functionally identical and can be obtained by reversing the order of the functions shown and substituting the antonym for the words retract (i.e., extend), release (attach), to (from), and dock (undock).

### 3.2.2 Functional Analysis of Docking Modes

A functional comparison of the two docking modes considered, i.e., orbiter to station docking mode and free-flying module docking mode, shows that the differences occur in the number and order of dockings which occur rather than the details of how the docking is done. Each of the three docking systems considered can be used with either of the docking modes.

The two docking modes including three variations discussed in Section 3.1.5 for the free-flying module mode are compared in Table 3-4 in terms of the three key functions of undock, free-fly, and dock. The table describes a typical orbiter mission in which the orbiter delivers one module to the station and returns another station module to earth.

It is apparent from the table that the Space Based and Ground Based Mini-Tugs involve the most operations (15 and 9 operations, respectively), as opposed to 6 operations each for the orbiter to station and integral systems free-flying modes.

If the comparison is confined to the space station assembly operations only, in which modules are delivered to the station but not returned to the orbiter, only the items indicated by the asterisks are involved. The comparison now shows that the space based and mini-based tug, each require six functions, and the integral systems module and orbiter to station modes three each.

### 3.2.3 Hazards Common to All Docking Systems and Modes

Hazards were identified by considering the potential effects of possible equipment failures, operational errors, unexpected environments and major malfunctions or accidents during each of the functions identified in Sections 3.2.1 and 3.2.2. The hazards fell into two categories: those common to all the docking systems and modes considered, and those specific to individual systems or modes.

The hazards common to all systems and modes are identified by 2.1.XXX numbers, and are as follows:



Table 3-4. Functional Comparison of Orbiter to Station  
and Free-Flying Module Docking Modes

Function	MODE			
	Orbiter to Station (Direct Dock)	Free-Fly Module		
		Integral Systems Module	Space Based Mini-Tug	Ground Based Mini-Tug
o Undock from station			X	
o Free-fly to orbiter			X	
o Dock to delivered payload module			X	
o Undock delivered payload module from orbiter		X	X	X
o Free-fly (or fly) to station	X	X	X	X
o Dock delivered payload module to station	X	X	X	X
o Undock from delivered payload module	X		Y	X
o Free-fly (transpose) to earthbound module	Y		Y	Y
o Dock to earthbound module	Y		Y	Y
o Undock earthbound module from station	Y	Y	Y	Y
o Free-fly to orbiter		Y	Y	X & Y
o Dock to orbiter		Y	Y	X & Y
o Undock from earthbound module			Y	
o Free-fly to station			Y	
o Dock to station			Y	
X = Deliver and dock a module. Y = Undock and return a module.				



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- 2.1.001 Impairment or visibility at critical moment during docking.
- 2.1.002 Loss of vehicle control prior to docking contact.
- 2.1.003 Loss of vehicle control after initial contact during docking.
- 2.1.004 Failure to inhibit attitude hold of one vehicle after capture during docking.
- 2.1.005 Loss of docking system function or control.
- 2.1.006 Failure of orbiter payload module deployment mechanism prior to docking.
- 2.1.007 Hardware protrusions in the docking tunnel.
- 2.1.008 Unsecured equipment and personnel during docking.
- 2.1.009 Degradation of life support system during docking.
- 2.1.010 Docking hatch opened when pressure equalization incomplete.
- 2.1.011 Electric discharge during initial docking contact.

The correlation of these hazards with the docking functions during which they can arise is shown by the x's in Table 3-5.

#### 3.2.4 Hazards Specific to Individual Docking Systems

Hazards identified by examination of the docking functions become more specific when consideration is given to each of the three docking systems previously described. These hazards are numbered as follows:

- 2.2.XXX Specific to the direct docking system.
- 2.3.XXX Specific to the extended tunnel docking system.
- 2.4.XXX Specific to the manipulator docking system.
- 2.2.001 Loss of vehicle control in close proximity to other vehicle during docking.
- 2.2.002 Loss of attenuation capability during docking.
- 2.3.001 Loss of vehicle control prior to docking contact by extendable tunnel.
- 2.3.002 Loss of vehicle control after capture by extendable tunnel docking system.
- 2.3.003 Loss of pressure in the pneumatic extension and energy absorption mechanism of the docking system.

Table 3-5. Correlation of Common Hazards with Docking Functions

Docking Function	Hazard										
	Impairment of Visibility	Loss of Vehicle Control Precontact	Loss of Vehicle Control Post Contact	Failure to Inhibit One Vehicle att. Hold	Loss of Docking System Function	Failure of Deployment Mechanism	Hardware Protrusions in Tunnel	Unsecured Equipment During Docking	Degradation of Life Support System	Pressure Not Equalized	Electric Discharge
Pre-Contact Flight Phase:											
Acquisition	X	X							X		
Gross Orientation	X	X						X	X		
Stationkeep.	X	X							X		
Deploy dock. sys.	X	X			X	X			X		
Fine orient.	X	X						X	X		
Final Clos.	X	X			X	X		X	X		
Contact Phase:											
Energy Atten.			X		X			X	X		X
Post Contact Phase:											
Capture			X	X	X			X	X		X
Attitude			X	X	X			X	X		
Align.											
Draw down			X	X	X			X	X		
Rigidizing			X	X	X		X	X		X	
Undocking Phase											
Unrigidizing			X	X	X		X			X	X
Separation			X		X		X	X		X	
Recycle Sys.			X			X					

- 2.4.001 Loss of vehicle control prior to capture by manipulator during docking.
- 2.4.002 Loss of vehicle control after capture by manipulator during docking.
- 2.4.003 Loss of manipulator joint motor control during docking.
- 2.4.004 Loss of manipulator computer aided control system during docking.

### 3.2.5 Hazards Specific to Individual Docking Modes

The hazards associated with each of the docking modes are generally the same; i.e., the "common" hazards. This does not mean that all the docking modes are to be considered equally safe, since the criticality of the same hazard can be very different depending on the sizes and configuration of the vehicles involved. Thus failure to inhibit attitude hold after capture may be merely an inconvenience when a free flying module docks to an orbiter or a station, since the bending moments induced at the docking interface will be small; but the same hazard occurring when the orbiter docks to the station could be catastrophic, and result in structural failure, because of the large control moments and inertias involved. Similarly, loss of vehicle control prior to docking is much more likely to result in contact and damage in the orbiter-to-station mode, because of the complex geometries and large masses involved, than in the free-flying module mode.

Although there is no way of quantifying the effects of geometric and mass differences in the docking modes, the criticality of the "common" hazards must in general be judged to be more severe for the orbiter-to-station mode than for the free-flying module mode.

No additional hazards have been identified as peculiar to the orbiter-to-station docking mode.

The free flying module docking mode has the same basic set of hazards as any docking maneuver unless it is unmanned and controlled either by computer aided systems or by remote human control. The requirement that the free flying module must be deployed from the cargo bay is not an additional hazard; it only increases the potential of vehicle damage if vehicle control is lost in close proximity to the orbiter. This hazard has been identified as common to any docking maneuver.

The following additional hazards are identified with free flying modules:

- 2.5.001 Loss of Communications/Command capability during docking by unmanned free flying module.
- 2.5.002 Loss of propulsion or control capability during docking by manned free flying module.
- 2.5.003 Loss of life support capability during docking by manned free flying module.



The use of a mini-tug as a maneuvering vehicle to dock with and free-fly a cargo module to the station does not introduce additional hazards than any other docking mode. There are, however, more docking operations required, as discussed earlier, so that the occurrence of an accident is more likely.

### 3.3 COMPARISON AND EVALUATION OF DOCKING SYSTEMS

In order to determine the preferred docking system or docking mode from a safety point of view, a comparison and evaluation must be made between the different options considered based on the important safety evaluation criteria. Universal standards for criteria to measure or evaluate safety do not exist. Therefore a number of different criteria are used in what follows to compare the various systems and modes.

For the docking systems, these comparisons were made on the following criteria.

- Number of hazards
- Criticality of hazards
- Risk, or combination of probability and criticality
- Operational complexity
- Design impact of applying the safety requirements and guidelines
- Residual hazards

The results of these comparisons are presented in Section 3.3.1. The evaluation of the systems, i.e., deciding the relative merits of the options (from a safety point of view) depends on the relative importance placed on each of the above six criteria, and is covered in Section 3.3.2. Final conclusions and recommendations are presented in Section 3.6.

Since 11 of the hazards identified, their effects, and the resulting requirements and guidelines are common to all three docking systems, the comparisons in the following sections are confined to those hazards which are specific to each of the three systems. It is these differences which will determine the preferred system.

#### 3.3.1 Comparison of Docking Systems

A comparison of the number of hazards that are directly associated with the three candidate docking systems is as follows:

- Direct docking system - 2 hazards
- Extendable tunnel system - 3 hazards
- Manipulator docking system - 4 hazards

A comparison based on how critical the hazards are, must be derived from levels of criticality. These may be defined as follows, for purposes of this study, in decreasing order of severity.

- Loss of personnel
- Vehicle damage
- Docking system damage

This assumes that the docking system is maintainable or replaceable, so that damage to the docking system is less critical than other, possibly irreparable, damage to the spacecraft.

The criticality of the hazards which are specific to the docking systems is shown in Table 3-6. "Personnel loss" hazards are identified for the stationkeeping and dual manipulator methods of the manipulator system. The dual dock manipulator system has four vehicle damage hazards, compared to one each for the direct docking and extendable tunnel systems.

Table 3-6. Criticality of Hazards Specific to Docking Systems

Docking System				
Criticality	Direct Docking	Extendable Tunnel	Manipulator	
			Dual Dock	Station-Keep. & Dual Manip.
Loss of personnel				2.4.003 2.4.004
Vehicle damage	2.2.001 2.2.002	2.3.003	2.4.001 2.4.002 2.4.003 2.4.004	2.4.001 2.4.002
Docking system damage		2.3.001 2.3.002		
(Numbers identify hazards - see Section 3.2)				

A further refinement can be made by comparing not only the criticality of each hazard, but also the relative probability of occurrence. Such estimates are at best subjective, but should nevertheless be factored into a full evaluation. Since only relative probabilities are required for comparison, these are judged merely as "low", "medium" and "high." The combination of criticality and probability can only be shown as a matrix. Based on the assumption that the recommended guidelines and requirements are met, the judgements on the hazards of the three systems are as follows:

The results of these comparisons are summarized in Figure 3.3-1. The manipulator system thus has the worst combination of number of hazards, criticalities and probabilities of occurrence, with the stationkeeping and dual manipulator methods having two hazards with the worst possible combination of criticality and probability.

Another comparison is on the basis of the operational complexity. The system with the most operations is exposed to the greatest risk. The significant operations were taken to be the free fly maneuver, the attachment and detachment of a manipulator to a module, and the docking and undocking of a module, including rigidizing, at a docking port. The comparison is shown in Table 3.7. This table covers the normal resupply docking, when a new module is being delivered to the station and another one is returned to the orbiter for return to earth.

The three methods for the manipulator docking system are shown separately, since they differ in the number of operations. There is also a possible variation, as shown by the asterisked numbers, according to

Table 3-7. Number of Operations for Different Docking Systems

System	Operation		
	Free-fly	Attach/Detach	Dock/Undock
Direct Docking	2	-	2
Extendable Tunnel	2	-	2
Manipulator			
Station-keeping	1-2*	2	1
Dual dock	1-2*	3-4*	2-3*
Dual manipulator	1-2*	3-4*	1
*The higher number applies when the orbiter must be repositioned to reach the module being returned.			



SYSTEM	HAZARDS SPECIFIC TO DOCKING SYSTEM	COMPARISON					
		PROBABILITY			CRITICALITY		
		LOW	MEDIUM	HIGH	DOCK SYS. DAMAGE	VEHICLE DAMAGE	PERS. LOSS
DIRECT	LOSS OF CONTROL IN CLOSE PROXIMITY TO OTHER VEHICLE		X			X	
	LOSS OF ATTENUATION CAPABILITY	X				X	
EXTENDABLE	LOSS OF CONTROL PRIOR TO DOCKING CONTACT		X		X		
	LOSS OF CONTROL AFTER CAPTURE		X		X		
	LOSS OF PRESSURE IN TUNNEL		X			X	
	LOSS OF CONTROL PRIOR TO CAPTURE BY MANIPULATOR		X			X	
MANIPULATOR	LOSS OF CONTROL AFTER CAPTURE BY MANIPULATOR		X			X	
	LOSS OF MANIPULATOR JOINT MOTOR CONTROL			X		X <sup>(1)</sup>	X <sup>(2)</sup>
	LOSS OF MANIPULATOR COMPUTER AIDED CONTROL			X		X <sup>(1)</sup>	X <sup>(2)</sup>

(1) Dual dock docking method

(2) Stationkeeping and dual manipulator docking methods

Figure 3.3-1. Probability and Criticality of Docking System Hazards





whether the returned module can be reached by the orbiter manipulator without repositioning from its delivery position, or whether the orbiter must reposition itself by a free flying maneuver to reach the returned module.

The direct docking and the extendable tunnel systems involve two free fly, and two dockings and undockings each. The manipulator docking system involves, in addition, the attaching and detaching operations of the manipulator, and a variable number of free fly, docking and undocking maneuvers, depending on the method used and the geometry involved. No clear-cut statement can be made that one system requires more operations than another.

In order to compare the docking systems on the basis of design impact of applying the safety requirements and guidelines, only those safety requirements and guidelines which are specific to one or other of the systems and which have a significant impact on the design need be considered. It is assumed that each system is designed in the first place to perform its normal functions and that each system can perform these functions equally well. Thus differences in weight, complexity, cost, or other factors which are inherent to the systems are not evaluated. It is only the additional features required for safety (as identified in the hazards/emergency analyses) that are evaluated. Significant design impact is considered to mean the addition of mechanisms, motors, actuators, and similar levels of hardware, for safety reasons. Addition of wiring, sensors, electronics redundancy, additional software requirements or special procedures are not considered significant design impact.

Analysis of the eleven "common" hazards/emergency analyses (2.1.001-2.1.011) shows that the impact of the requirements and guidelines is essentially of equal impact on the three systems. Furthermore, many of the requirements and guidelines from the "specific" hazard/emergency analyses are the same as for the "common" ones. Of the remaining "specific" requirements and guidelines, the following are considered to have significant design impact; these refer to the extendable tunnel and manipulator docking systems:

#### Extendable tunnel

2.3.003-2. Extendable docking systems shall be designed so that the extension mechanism shall retain sufficient rigidity following any single failure to prevent uncontrolled vehicle motion or contact.

#### Manipulators

2.4.003-3. Arm joints shall be designed to lock on indication of joint motor failure. Lock shall incorporate a slip clutch capability to prevent structural failures.

2.4.003-9. Two or more manipulators shall be provided in a manipulator docking system. Each manipulator shall be capable of performing docking by itself, and shall also be capable of continuing any docking function in the event of a failure of the other manipulator at any stage of the docking.

2.4.003-10. An emergency jettisoning capability shall be provided for manipulators, independent of the normal manipulator system. This shall be capable of jettisoning the manipulator following a failure

or accident which does not allow stowage of the manipulator and configuring the orbiter for reentry and landing.

Furthermore, if the manipulator docking system is considered for transferring personnel between orbiter and station using the stationkeeping or the dual manipulator methods, the following two additional requirements become applicable. Because their purpose is to safeguard the transferred personnel, they have a major design impact.

2.4.003-6. Modules which are used for personnel transfer by manipulator docking shall be provided with EVA pressure suits for all on-board personnel, and with EVA exit capability so that the personnel can escape to the orbiter or the space station in the event the module becomes stranded between vehicles by a manipulator failure.

2.4.003-7. Modules which are used for personnel transfer by manipulator docking shall provide emergency life support for all on-board personnel, until they can escape or be rescued by external means in the event the module becomes stranded between vehicles by a manipulator failure.

The last comparison is in terms of residual hazards. Of the "specific" hazards identified, all have been judged to be residual hazards; i.e. even after the recommended requirements and guidelines have been implemented, the possibility of damage to vehicle or docking system cannot be eliminated. The comparison therefore shows:

Direct docking system - 2 residual hazards  
Extendable tunnel system - 3 residual hazards  
Manipulator docking system - 4 residual hazards

### 3.3.2 Evaluation of Docking Systems

The previous section, 3.3.1, presented a comparison of the three docking systems according to six criteria. In these sections these results are evaluated; i.e. a judgment is made on the relative importance of the results of the comparisons, in order that recommendations may be made from the safety point of view.

The most significant safety consideration is the safety of the personnel. There are appreciable personnel safety implications in using the manipulator docking system in the stationkeeping and dual manipulator methods to transfer personnel between orbiter and station. These methods can lead to stranding personnel in the transferred module if the manipulator fails, with the further potential of personnel loss if the malfunction cannot be corrected in time or if the personnel cannot escape or be rescued. The



other systems, and the dual docking method of the manipulator system do not have the risk of personnel loss during personnel transfer, since personnel will only transfer through the docking port after rigidizing of the orbiter to station, when either vessel can provide adequate personnel safety.

The same issue can be considered from the point of view of how much of a design impact it is to make these two methods adequately safe for personnel transfer. To do this, the two requirements, 2.4.003-6 and -7, identified in Section 3.3.1, for EVA capability and for emergency life support on each module used for personnel transfer, must be met. This is undoubtedly a very major design impact. The weight and volume of implementing these requirements would be chargeable to the module, thus reducing the useful payload and available volume. Furthermore, these requirements cannot absolutely remove the risk, since the nature of the failure and the escape or rescue time cannot be definitely established. This risk of personnel loss therefore remains a residual hazard of the manipulator docking system used in these two methods for personnel transfer.

These must therefore be regarded as strong safety disadvantages. The fact that only one docking and undocking is involved in each normal station resupply mission compared with 2 or more for the other systems is not considered a significant safety advantage, since it merely affects the probability of a hazard, to a degree which is not known or measurable.

A comparison of the three systems, excluding the manipulator system for personnel transfer in the two methods just discussed, does not show any other strong safety reasons for preferring one system over another. All three systems show the same criticality, with the potential of causing vehicle damage. The manipulator docking system (in the dual docking method) exhibits more modes for causing damage, and with a relatively higher probability, than the other systems, because of the mechanical and control complexity of the manipulator itself. If control of either the manipulator or of one of the vehicles is lost at a crucial phase, damage is quite likely because of the large volume swept by the manipulator envelope. The specific safety requirements, although fairly significant, would not noticeably affect the development of the system.

The direct docking system, on the other hand, has the one relatively severe risk that a control system failure when the two vehicles are close to each other, can result in inadvertent contact and damage. The higher contact velocity of this system (up to 0.3 m/sec, 1 ft/sec) compared to the manipulator system (up to 0.03 m/sec, 0.1 ft/sec) could be expected to result in both less reaction time for corrective action and more damage.

The extendable tunnel system appears, from the comparison, to have the lowest probability of causing damage. This occurs because of the relatively large separation of the vehicles (about 3 m, 10 ft) during the critical initial contact and capture phases of the docking maneuver. This makes the system relatively tolerant to approach condition errors and to control system



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failures, allowing adequate time for crew diagnosis and corrective action. In addition, the most critical failure mode identified is failure of the extension mechanism, which is assumed to be a pneumatically inflated tube. Should a different extension mechanism be used which has a more benign failure mode, the extendable tunnel system would be quite attractive from the safety point of view, exhibiting a lower criticality than the other systems. It must be remembered however that this system has not been adequately studied or developed, in a fully developed and practical system which are not apparent at present.

### 3.4 COMPARISON AND EVALUATION OF DOCKING MODES

Because the orbiter to station and free flying module modes differ at an overall concept level rather than a detailed system level, the comparisons and evaluation are made on different criteria from those for the docking systems. These criteria are:

- o The potential for crew injury or loss
- o The potential for vehicle loss
- o The potential for vehicle damage
- o The cost and payload impact of required safety

These criteria are discussed and evaluated as a whole for each docking mode, rather than compared individually for the two docking modes. This section is therefore arranged in an evaluation section for each of the two modes, and concluded with a comparison of the two modes.

#### 3.4.1 Evaluation of Orbiter-to-Station Docking Mode

The hazards identified for the orbiter to station docking mode have the potential of causing major damage to the orbiter and/or the station, but do not directly lead to personnel injury or loss. The damage would result from inadvertent contact of parts of the structure not intended to make contact. Because both vehicles are large and have complex geometries, with many protruberances, such as cargo bay doors, wings and manipulators on the orbiter, and solar panels, antennas and experiments airlocks on the station, almost any unprogrammed motion can lead to contact and damage.

While the damage to the structure or equipment would not normally be expected to lead to personnel injury or loss, this cannot be ruled out as an eventual consequence of the damage. For example, if the aerodynamic surfaces of the orbiter are damaged so as to preclude reentry, and escape or rescue is not possible within the time constraint imposed by the life support capability, then crew loss would result. Or, again, if a massive penetration of the pressurized structure of the station occurs, personnel loss from depressurization is possible.

Generally, however, the effects would be limited to damage to the vehicle, and the potential for personnel injury or loss should be assessed as a second order effect. The proximity of the orbiter and station, either of which can provide for the long term safety of personnel (one by return to earth and the other by virtue of its inherent long duration capability), and the assumed EVA capability virtually ensure that personnel who survive the immediate accident can be safeguarded.

The possibility of loss of one vehicle following a docking accident is quite real, however. The orbiter is vulnerable in a number of ways. The cargo bay doors must be closed before reentry; damage to the closing mechanism, or to the doors themselves, could result in the ingestion of hot reentry gases, leading to thermal degradation of the internal structure. The wings, fuselage



and tail surfaces are part of the aerodynamic configuration, and damage can affect the stability and control of the vehicle in the atmosphere. The crew cabin also is near the docking port, and damage to that could preclude return to earth. If an assessment of the damage prevents return to earth, a very complex and costly rescue and repair shuttle mission would be required, probably with much EVA maintenance. In extreme cases the orbiter would be written off as a complete loss, and the rescue mission would concentrate on saving the personnel and placing the orbiter on a safe reentry orbit.

The space station, being modular in nature, is much more tolerant to damage. Damage would generally be confined to one module, and this could be returned to earth in the orbiter for repair or replacement. This could be quite difficult, however, if the affected module were the core module, since all other modules are attached to it. In such a case the space station may be temporarily abandoned, and a new core module brought up in due course. The space station would then be re-assembled about this module, and the damaged core module returned to earth. Damage to the solar arrays (relatively likely because of the large area exposed) could similarly lead to temporary station abandonment.

No requirements or guidelines have been identified in the hazard/emergency analyses which apply specifically only for the orbiter to station docking mode. The "common" requirements and guidelines are equally applicable to the free flying docking mode, and have equal design and cost impact when applied to either mode. The impact of safety on the cost and payloads for the orbiter to station docking mode is therefore minimal.

#### 3.4.2 Evaluation of Free-Flying Module Docking Mode

The free flying module docking mode has a very definite potential for personnel loss. If loss of the propulsion, control or life support capability occurs while the module is free flying between orbiter and station with personnel onboard, personnel loss can occur. Escape can only be effected by EVA to the orbiter and station. Rescue is possible by the orbiter, but only if the module can still be stabilized (for docking) and if adequate life support capability remains. The possibility of personnel loss must therefore be rated as relatively high. In contrast to the orbiter to station docking mode, loss of personnel can follow directly as a consequence of a system failure, and does not depend on a propagation of unlikely effects.

The potential for personnel loss appears to be about the same for the integral systems module, space-based mini-tug or ground-based mini-tug approaches. All three involve one free flight of the manned module for each manned module transfer maneuver, and therefore expose the personnel to equal risk. The probability of propulsion, guidance and life support systems failure which could affect personnel safety are essentially the same whether this equipment is located integrally on the module or in the mini-tug. The mini-tugs themselves have more flights than the integral systems module (5 flights for the space-based and 3 for the ground-based mini-tug, compared with 2 for the integral systems module). However, the number of manned flights is the same (2 in each case). The risk to personnel is the same in each case.

Providing a spare mini-tug in the program provides a back-up rescue capability, but this is available by the orbiter, anyway. It does not reduce the risk from a failure which causes the free flying module to lose attitude control, to tumble out-of-control, or to fly off in a trajectory beyond the propulsive capability of the spare mini-tug to catch up and return it.

In this respect, the redundancy provided by the spare mini-tug is far better employed as on-board redundancy of the critical systems, so that any failure (except a catastrophic failure which destroys the whole mini-tug) can be promptly counteracted, irrespective of the vehicle's motion. This conclusion, that built-in redundancy is safer than a spare vehicle, applies equally to the integral systems module and the two mini-tug concepts.

The possibility of an inadvertent collision between the free flying module and the orbiter or space station is about as likely as for the orbiter to station docking mode. The resultant damage, however, is likely to be much less, for two reasons. Firstly, the geometry of a single module docking to orbiter or station is much simpler, so that fewer points on the two vehicles will come into contact. Secondly, the mass of a free flying module is only about 10 to 20 percent of the mass of either orbiter or station, so that the energy involved in the collision is relatively small.

As for the orbiter to station docking mode, inadvertent collision could lead to personnel loss, but only as a secondary effect. The probability of personnel loss on the station or orbiter must be considered less than on the orbiter to station mode, because of the expected smaller potential for damage. The probability of personnel loss on the free flying module is higher than on either of the two large vehicles, however, because the free flying module is more vulnerable to accidents. A given penetration of the structure will lead to more rapid depressurization, because of the smaller volume; dual pressure volumes are not likely on the free flying module; and the duration of the prime and the emergency life support capability will be of the order of hours rather than days, as on the orbiter and station.

When considering the impact of safety on the design complexity of the free flying module docking mode, this must be judged to be a major impact. The requirement for a life support system on the module is not considered as a safety requirement, as it is needed for the normal vehicle function of transporting personnel. The redundancy required in this system, the added redundancy in the control, power, propulsion and communication systems, the EVA suits and EVA capability, and the emergency life support capabilities, are directly attributable to safety. These are reflected in the hazard/emergency analyses referring specifically to the free flying module docking mode (No.'s 2.5.001 to 2.5.003). These requirements considerably affect the net payload capability of each free flying module, as well as the volume availability for cargo.

Typical weights and volumes for these safety requirements are shown in Table 3-8 for a 6-man vehicle. 534 kg (1180 lb) and 3 m<sup>3</sup> (106 ft<sup>3</sup>) of useful cargo are lost. This assumes that the EVA suits are relatively lightweight emergency suits, with a simple oxygen purge system, capable of one-half hour life support, rather than a normal portable life support system.

**Table 3-8. Typical Increments in Weights and Volumes for Meeting Safety Requirements on a Manned Free-Flying Module**

Item	Weight kg (lb)	Volume m <sup>3</sup> (ft <sup>3</sup> )
<b>Redundant Systems</b>		
Communications	27 (60)	.04 (1.5)
Power (4 hrs)	54 (120)	.06 (2)
Environmental Control (4 hrs)	36 (80)	.07 (2.5)
Reaction Control (20 lb jets)	27 (60)	.06 (2)
6 Pressure Garment Assemblies and Oxygen Purge Systems	190 (420)	.57 (20)
2-Man Airlock	159 (350)	2.11 (75)
Emergency Life Support (48 hrs)	41 (90)	.09 (3)
<b>Total</b>	<b>534 (1180)</b>	<b>3.00 (106)</b>

#### **3.4.3 Evaluation of Free-Flying Module Docking Mode used for Unmanned Operations Only**

A considerably different safety evaluation of the free flying module docking mode arises if this mode is used only for transferring unmanned payloads, and the orbiter to station mode is used when personnel transfer between the vehicles is involved. This combined mode could be practical if a mini-tug has been developed for other purposes and is available for docking unmanned payloads, or if some orbiter payloads, such as a space tug, have the propulsion and control capability built into them, and require transfer from the orbiter to station and vice versa.

The advantages associated with docking a smaller mass to the orbiter or station, and of the simpler geometry reducing the potential for damage on collision, apply to this mode in the same way as described for the (manned) free flying module mode in Section 3.4.2. The disadvantages of having a relatively high potential of personnel loss, and of severely impacting the weight and volume of the transported payload, no longer apply, however. Some equipment, namely control systems, propulsion, communications, etc., would still require redundancy (see Hazard/Emergency Analysis No. 2.5.001), to ensure the whole vehicle is not lost. But this is a general system safety requirement, applicable to the module because it is a free flying module, and is not directly attributable to the docking mode.





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This mixed mode therefore provides safety advantages over the orbiter to station docking mode on its own, and over the free flying module docking mode on its own. These advantages apply so long as the free flying module is not used at all for personnel transfer. The orbiter to station docking mode can be used for the transfer of personnel or of unmanned cargo, as required. The overall risks are minimized, however, when the orbiter to station mode is used for personnel transfer, to minimize risks to personnel, and all unmanned transfer is performed by the free flying mode, which minimizes risks to the orbiter and station.

The disadvantages of this mixed mode are not safety disadvantages, but are associated with the program complexity of having two docking modes in the program. The docking system can be designed to handle upto a 10:1 range in docking masses, as would be required, and does not need different energy attenuation systems for the two cases. Of course, if the free flying module capability or the mini-tug were needed only for increasing the docking safety, the cost of these developments would then have to be considered against the incremental safety which is obtained, and the concept would be very unattractive; but if the systems are developed for other reasons, this additional safety is obtained for a very small cost only.



### 3.5 EMERGENCY DOCKING CONSIDERATIONS

The reasons for emergency docking, establish certain requirements that will determine which of the three docking concepts should be favored from an emergency docking standpoint. The reasons for emergency docking that appear to cover the majority of possibilities are as follows:

1. A time critical malfunction of a system in either manned/passive or manned/active vehicles, that if docked to the other, would provide succor or permit mission continuance.
2. Retrieval of a disabled, unmanned, free flying, module or disabled unmanned station for the purpose of salvage or deorbit of debris.
3. Time critical transfer of disabled crew which could prevent fatality.
4. Time critical transfer of supplies which would prevent crew disability.

Conditions that may complicate an emergency docking, other than system malfunctions or disabled crew, are the requirement to have the sun in a particular orientation during docking and the requirement to dock at night.

The time critical emergency docking reasons (3 out of 4), by their nature, would favor the docking system and mode requiring the shortest, operational time line for the docking maneuver. A fair measure of time line is the number of functions a docking system must perform to complete the docking maneuver.

This would favor the orbiter to station docking mode over the free flying module mode, and the direct docking system over the extendable tunnel and manipulator docking systems. The free flying module mode, in particular, considerably extends the total time from initiation of the docking maneuver to its completion.

However, the importance of reducing the docking time in evaluating the merits of the various docking systems and modes must be kept in perspective. Given that a time critical emergency has occurred, the probability that it occurs when the orbiter and station are positioned and configured so that they can initiate a docking maneuver immediately is very remote. It is only in that unlikely circumstance that the time to effect the rescue is significantly affected (as a percentage) by a reduction in the docking time. For example, if the emergency occurs in the space station, the chances are that no orbiter is in space at the time. A shuttle rescue mission may typically take 10 hours from an alert to rendezvous. The difference between one method of docking and another may be 15 minutes (in an emergency mode), and this time is unlikely to be critical to the success of the rescue. Similarly, even if an orbiter is in orbit at the time, it may be two hours before orbits can be phased and matched; a large time compared with the 15 minutes difference between the docking methods.



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When considering the two docking modes, the time advantage is clearly in the orbiter to station docking mode. In this case the added time for deploying and free flying a module to the distressed vehicle could be up to a few hours, particularly if a mini-tug is involved, and this could be a significant addition to the total time available.

The two emergency docking situations that involve spacecraft systems malfunctions could be too hazardous for an approach with a direct docking system. If, for example, the target vehicle has low attitude stabilization and cannot maintain "attitude hold", resulting in a tumbling rate, it may be impossible for the active docking vehicle to chase the target docking port in both rotation and translation. If a free tumbling vehicle rotates about its center of mass, a docking port, located some distance away from the center of mass will have a circular motion, and will be oriented at some angle to the plane of rotation. Of the three docking systems considered, only the manipulator has the capability to add its dexterity to that of the active vehicle in the task of capturing a tumbling target vehicle. Such a maneuver would, in general, require degrees of freedom not necessarily built into the manipulator, and could be quite hazardous if the tumbling axis is changing rapidly. This problem is discussed in Section 2.0 of Volume III.

If the target vehicle is inadvertently spinning about an axis through or near the docking port, the manipulator docking system is again the only concept, of the three, that could spin synchronize its capture interface with respect to the turning target vehicle docking port, and de-spin and dock. In either the tumbling mode or the roll spin mode, the manipulator would also be favored, from a safety standpoint, because of its capability to effect capture at a distance.

If the emergency consists of the passive vehicle having lost attitude hold capability and it is either tumbling very slowly, within the design capability of the docking system, or is subject to unpredictable motions due to venting, the direct docking system would be the least desirable, because of the close approach of the two vehicles. The manipulator system would offer the best and safest method, with the extendable tunnel an intermediate choice.

In summary, emergency docking considerations favor the orbiter to station docking mode over the free flying module mode because of its quicker time response; although the direct docking system is the quickest system, the manipulator system has advantages in increased separation between the vehicles and in capability to deal with out-of-control vehicles.

### 3.6 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions reached from the safety evaluation of the docking systems and modes, and presents the resulting recommendations.

The conclusions reached on the docking systems are summarized as follows:

- Each of the three docking systems -- direct docking, extendable tunnel and manipulator -- can be made adequately safe.
- The "docking vehicle active" and the "docking vehicle passive, docking system active" methods of using the extendable tunnel docking system show no significant safety differences.
- The station keeping and the dual manipulator methods of using the manipulator docking system have the potential of personnel loss in the event of loss of manipulator control before a manned attached module is docked. This remains a residual hazard even when complex emergency life support requirements are added to the manned modules. The dual docking method requires more operations to effect docking, but does not have the potential for loss of personnel.
- All three docking systems have the potential of damage to the docking system and damage to the vehicles. The damage to the spacecraft could, in certain circumstances, be critical enough to result in loss of vehicle or loss of personnel.
- The direct docking system has the greatest potential for inadvertent collision because of the close proximity of the docking vehicles.
- The manipulator docking system has the minimum potential for inadvertent collision between vehicles because of the relatively large separation distance at initial capture, but has more failure modes which can result in inadvertent contact and damage.
- The direct docking can perform a time critical emergency docking quicker than the other systems. The manipulator docking system has more potential for docking with an out-of-control, tumbling or spinning spacecraft.
- The hazards and risks of the three systems are not equally well understood because of the different development status of the systems. The direct docking system is relatively well understood from Gemini and Apollo experience, the manipulator system has been defined to some extent in the Shuttle Phase B studies, but has not been tested or simulated at the time of this study, and the extendable tunnel system is only in a conceptual stage.



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- The safety advantages and disadvantages of the three systems are sufficiently balanced and uncertainties in the current system definition are such that a ranking of the system from the safety point of view cannot be made at present.
- If the docking systems, when developed, operate as assumed in the study, i.e., without any major additional complications in the design or additional hazards, then the extendable tunnel system appears to require the least attention to make it adequately safe, and the manipulator system the most.

The conclusions reached on the docking modes are summarized as follows:

- The free flying docking mode has a potential for personnel loss when used to transfer personnel between orbiter and station. The necessary safety requirements for 6 men on the free flying module reduce the payload capability by 500 kg (1200 lb) and 3 m<sup>3</sup> (100 ft<sup>3</sup>), but the potential for personnel loss remains a residual hazard.
- The free flying module docking mode precludes the possibility of a single accident resulting in loss of both the orbiter and station.
- No significant safety differences exist between the integral systems module, space based mini-tug and ground based mini-tug methods of using the free flying module docking mode.
- The orbiter to station docking mode has more potential of causing major damage to the orbiter and/or station than the free-flying docking mode but does not directly lead to personnel loss. Loss of personnel or loss of a vehicle as a result of the damage is possible but not likely.
- Use of the free flying mode for transferring only unmanned modules between orbiter and station eliminates the potential of personnel loss during transfer. It also has a reduced potential for vehicle contact and damage compared to the orbiter to station docking mode because of the simpler geometry and smaller docking energy involved.
- The orbiter to station docking mode provides significantly quicker docking than the free flying module mode in the event of a time critical docking requirement.

The recommendations that result from this task are based on the following precedence of safety selection criteria:

- A system or mode which has the lesser potential for personnel loss is preferred.
- Of the remaining choices, the system or mode in which the safety requirements and guidelines can result in a significantly lesser risk (in terms of probability and severity of damage) is preferred.
- Where the requirements and guidelines result in essentially equal risk, the choice in which the requirements and guidelines result in significantly less design impact is preferred.
- The capability to better deal with an emergency situation is considered in the recommendations, but is weighted relatively lightly because there is no clear-cut advantage to any of the systems or modes, and because of the low probability of an emergency docking being required.

These recommendations are:

- The direct docking, extendable tunnel, and manipulator docking systems should all be considered as acceptable docking systems from the safety point of view.
- The station keeping and dual manipulator methods of using the manipulator docking system should be rejected as practical options for personnel transfer in normal operations because of their high potential for personnel loss. The methods are acceptable for transfer of unmanned modules, or for emergencies.
- The use of the free-flying docking mode for the transfer of manned modules should be rejected for normal operations because of the potential for personnel loss. The mode may be used in emergencies.
- The orbiter-to-station docking mode should be considered acceptable from the safety point of view with any of the acceptable docking systems.
- If mini-tugs (such as remote maneuvering units) or modules with self-contained propulsion, control and docking capabilities (such as the space tug) are developed for other purposes and are available, their use in transferring unmanned modules or payloads between orbiter and station should be considered as an acceptable docking mode. Use of this free-flying module mode for unmanned payloads in conjunction with the use of the orbiter to station mode for all manned modules has significant safety advantages.



### 3.7 RESIDUAL HAZARDS AND HAZARDS RESOLUTION

This section summarizes the hazards identified in Sections 3.2.3 to 3.2.5 and their resolution as defined in Section 2.0, and presents the resulting requirements for supporting research and technology.

#### 3.7.1 Resolution of Identified Hazards

The disposition of the 23 hazards identified in Sections 3.2.3 to 3.2.5 is shown in Table 3-9. This shows the judgements of the investigators as to which hazards should be resolved by implementation of the recommended requirements and guidelines; which are residual hazards; which of the residual hazards represent acceptable risks; and which require supporting research and technology (SRT) or must at present be considered as unresolved safety issues. This hazards resolution has been performed in accordance with the procedures and definitions described in Appendix A.

#### 3.7.2 Supporting Research and Technology Requirements

The supporting research and technology requirements resulting from the areas of uncertainty of this task are listed below. The main originating hazards/emergency are indicated in parenthesis.

- The feasibility using a non-collision approach path during the docking maneuver until the approach velocity is reduced to within the docking attenuation capability should be investigated. Orbital mechanics, guidance, propellants penalties, optical aids and human factors should be considered, and detailed procedures developed. The risks and other factors of this method should be evaluated and compared with the direct (collision-path) approach.
- The dynamics of the docking maneuver under various nominal and worst case conditions should be investigated to assure that design requirements and operational procedures are available under all credible conditions to ensure the safety of the vehicles. Special attention should be given to vehicle conditions with maximum off-sets of the docking port from the center of gravity, and to control system or propulsion failures immediately before or after contact.
- Simulation studies of the dynamics and crew capabilities of the manipulator docking system should be conducted at the earliest possible time in order to understand the dynamic characteristics of the system and to identify and resolve hazards which are not apparent from conceptual studies. A safety analysis should be an integral part of such simulations.

Table 3-9. Hazards Resolution

Hazard No.	Hazard	Resolved	Residual	Acceptable Risk	SRT Requirements	Unresolved Safety Issue
2.1.001	Impairment or visibility at critical moment during docking.	X				
2.1.002	Loss of vehicle control prior to docking contact.		X		X	
2.1.003	Loss of vehicle control after initial contact during docking.		X		X	
2.1.004	Failure to inhibit attitude hold of one vehicle after capture during docking.	X				
2.1.005	Loss of docking system function or control.		X	X		
2.1.006	Failure of orbiter payload module deployment mechanism prior to docking.		X	X		
2.1.007	Hardware protrusions in the docking tunnel.	X				
2.1.008	Unsecured equipment and personnel during docking.	X				
2.1.009	Degradation of life support system during docking.	X				
2.1.010	Docking hatch opened when pressure equalization incomplete.	X				
2.1.011	Electric discharge during initial docking contact.	X				
2.2.001	Loss of vehicle control in close proximity to other vehicle during docking.		X		X	
2.2.002	Loss of attenuation capability during docking.	X				





Table 3-9. Hazards Resolution (Cont.)

Hazard No.	Hazard	Resolved	Residual	Acceptable Risk	SRT Requirements	Unresolved Safety Issue
2.3.001	Loss of vehicle control prior to docking contact by extendable tunnel.		X		X	
2.3.002	Loss of vehicle control after capture by extendable tunnel docking system.		X		X	
2.3.003	Loss of pressure in the pneumatic extension and energy absorption mechanism of the docking system.	X				
2.4.001	Loss of vehicle control prior to capture by manipulator during docking.		X		X	
2.4.002	Loss of vehicle control after capture by manipulator during docking.		X		X	
2.4.003	Loss of manipulator joint motor control during docking.		X		X	
2.4.004	Loss of manipulator computer aided control system during docking.	X				
2.5.001	Loss of Communications/Command capability during docking by unmanned free flying module.		X	X		
2.5.002	Loss of propulsion or control capability during docking by manned free flying module.		X			X
2.5.003	Loss of life support capability during docking by manned free flying module.		X	X		

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#### 4.0 PERSONNEL TRAFFIC PATTERNS, ESCAPE ROUTES AND ON-BOARD SURVIVABILITY

The purpose of this task was to analyze the personnel traffic patterns, escape routes, and on-board survivability from a safety standpoint for the orbiter with crew and passenger, sortie modules, and for the Modular Space Station. Among the primary areas of concern are (a) where separately pressure isolatable compartments are recommended, (b) whether dual access to each area is essential, (c) feasibility of dual escape routes and from each area to other areas not common to each other, (d) number, location and size of airlocks, and (e) location of hatches.

Three particular situations were investigated insofar as they concern the safety of the orbiter, sortie module, and space station personnel while in orbit:

- Normal operations, in which no emergency exists, were assessed in order to specify recommendations which would minimize the danger of crew injury should an emergency arise.
- Emergency operations, where an emergency has arisen.
- Extravehicular and Intravehicular activities (EVA) and (IVA), where such activity is required in the performance of experiments, vehicle maintenance or repair, or as a result of an emergency situation.

Generalized candidate configurations, typical of the many variations possible and those which have been or are being considered, were modeled for the orbiter, sortie modules, and Modular Space Station, and evaluated for their ability to satisfy safety requirements which evolved from an analysis of identified credible emergencies.

Specific baseline configurations, representative of those resulting from current advanced studies, were similarly evaluated for the orbiter, sortie modules, and space station in order to generate specifically applicable safety data for these vehicles which may materially effect their configuration or selection. In all cases, the minimum possible configurational changes from the baseline are recommended if required to meet safety criteria.

The analyses are presented in the following order:

- 4.1 Credible emergencies are identified for all the vehicle considered.
- 4.2 The orbiter is analyzed with an unmanned payload, and conclusions reached.
- 4.3 The analysis is extended to a manned sortie module attached to the orbiter, and conclusions reached.
- 4.4 The space station is analyzed, during normal operations, during assembly, and during resupply by an orbiter, and conclusions reached.



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Supporting analysis are presented in Appendix C. Hazard/emergency analyses performed for each baseline vehicle configuration, are contained in Appendix D. The requirements and guidelines are contained in Volumes IV and V.

#### 4.1 IDENTIFICATION OF CREDIBLE EMERGENCIES

The assessment of escape routes and compartmentation isolation required the identification of credible emergencies from which configuration oriented and supporting requirements could be generated through subsequent hazards analysis. The derivation of supporting requirements, such as those which are subsystems or operationally oriented, are necessary to make configurations acceptable, but are secondary objectives as compared to those requirements which drive vehicle compartmentation.

Existing safety documentation from the shuttle, modular space station, and RAM vehicle programs, the Boeing Space Station Safety Study, the Lockheed Safety studies, as well as documentation from previous tasks of this study were reviewed in order to establish credible emergencies to which vehicle compartmentation is sensitive. Catastrophic emergencies are not considered.

Eleven credible emergencies, which can be grouped into emergency classes which include fire/toxic environment, explosion, loss of pressure, inoperative hatches, and inoperative docking ports, resulted from this review, and are listed in Table 4.1-1 together with the corresponding assigned hazards analysis number and vehicle applicability.

Two types of fires can be defined to cover the spectrum of fires possible. A small fire is one which is of a magnitude which can be manually controlled and extinguished, does not require evacuation of the affected compartment, and causes only minor damage from the generated heat, smoke, fumes, and other combustion by-products.

Conversely, a large fire is one which requires evacuation of the affected compartment and possesses the potential of causing major damage to the vehicle and injury to the crew. It is the large fire which is of primary interest to this task, at a level which requires evacuation but does not result in crew injury.

In addition to the toxic environment created by a fire, atmospheric contamination can result from internal leakage (fluids leaking into the habitable environment), or from release of biological substances into the atmosphere.

A fire and toxic environment are combined into single emergency because they lead to the same evacuation and compartmentation requirements.

An explosion is considered a credible emergency due to the numerous potential explosive sources associated with the orbiter, station, and sortie modules such as propellants, high pressure gases, cryogenics, and experiment fluids. Many emergency situations can lead to emergency evacuation of a compartment. These situations are considered credible and therefore must be considered.



Table 4.1-1. Credible Emergencies

Hazard Analyses Number	Credible Emergency	Applicability			
		Orbiter	Sortie Module	Operational Station	Station in Assembly
3.1.001	Fire/toxic environment	X	X	X	X
3.1.002	Explosion	X	X	X	X
3.1.003	Emergency evacuation	X	X	X	X
3.1.004	Loss of pressure	X	X	X	X
3.1.005	Failure to open internal hatch between pressure isolatable volumes	X	X	X	X
3.1.006	Failure to open docking hatch after docking	X	X	X	X
3.1.007	Failure to close docking hatch before undocking	X	X	X	X
3.1.008	Inability to use docking hatch for EVA when EVA required	X		X	
3.1.009	Failure to close external airlock hatch when returning from EVA	X	X	X	
3.1.010	Failure to open internal airlock hatch when returning from EVA	X	X	X	
3.1.011	Failure to close IVA airlock hatch on depressurized/contaminated side or to open hatch on pressurized/habitable side when returning from EVA.			X	

Loss of pressure, as defined for this task means loss of pressure of a normally pressurized habitable volume. Rapid loss of pressurization can result from a collision between vehicles or between a vehicle and space debris, meteoroid penetration, or the inadvertent puncture of a vehicle pressure shell from within.

An inoperative hatch is a hatch which fails to open or close. Two types of hatches are involved in this emergency class. These are internal and external hatches. An internal hatch is used to isolate pressure volumes within a vehicle. An external hatch opens to space. A hatch which is included with each docking port is referred to herein as a docking hatch. A docking hatch can be used as either an internal or external hatch, depending on whether the docking interface is open to space or is closed to another vehicle.

The potential effects of four of these emergencies, namely, fire/toxic environment, explosion, emergency evacuation and loss of pressurization, required definition to classify the level of these emergencies to be considered for analysis. The primary assumptions for this task, as they affect reaction time, need to evacuate a compartment, injured/incapacitated personnel, restoration to a shirtsleeve environment, and potential to cause other credible emergencies are listed in Table 4.1-2.

Table 4.1-2. Assumed Effects for Variable Level Credible Emergencies

	Minimum Reaction Time (Mins)	Need to Evacuate Compartment	Injured/Incapacitated Personnel	Restoration to Shirtsleeve Environment	Can Cause Other Listed Credible Emergencies
Fire/Toxic Environment	0.5	Yes	No	Yes	Yes
Explosion	0	Yes	Yes	No	Yes
Emergency Evacuation	5	Yes	No	No	No
Loss of Pressurization	2-8	Yes	No	No	No

For example, the type of fire or toxic environment considered requires rapid (0.5 min) evacuation, but does not result in personnel injury, and allows for eventual return to the affected compartment. More severe accidents, which may injure personnel, or which do not allow shirtsleeve return to the affected compartment, are considered under "explosion" and "emergency evacuation".

## 4.2 SAFETY ANALYSIS OF ORBITER CONFIGURATIONS

Seven possible orbiter configurations are evaluated for their inherent capability to cope with the credible emergencies identified in Section 4.1. In addition to the level of emergencies considered with respect to reaction time and effect, which were given in Table 4.1-1, the following major assumptions were required to scope the analysis to within workable bounds. These are:

- Emergencies, other than hatch failures, are not considered on airlocks.
- De-orbit/return to earth requires crew participation in crew compartment.
- Rescue vehicle is not available.
- No double emergencies are considered.
- Airlocks are sized for two crewmen or all crewmen. If sized for all crewmen, they are treated and evaluated as a second volume.
- Passage of many personnel through an airlock, two at a time, is not acceptable.
- Airlock compartment for EVA can be crew compartment, passenger compartment, or airlock.
- Planned EVA will be accomplished through an airlock.
- Safety is not achieved via EVA.

Each of the seven candidate orbiter configurations, was evaluated within the constraints of the assumptions, to determine the operational options available to cope with each credible emergency. Analysis of the operational options resulted in secondary configurational, subsystems, and operational requirements necessary to make the option viable.

### 4.2.1 Candidate Orbiter Configurations

The baseline configuration of the orbiter is composed of an airlock, and a crew and passenger compartment as shown in Figure 4.2-1. This is the final configuration resulting from the NR Phase B study. The airlock, which is of a size to accommodate at a minimum, two suited crewmen, is located at the forward end of the orbiter, is fitted with a docking port, and an EVA hatch at the docking port. An emergency exit hatch, usable only on the ground because it leads to the closed wheel well when on-orbit, is located opposite the docking port. Accessibility to the crew/passenger compartment is provided via a hatch at the airlock to crew/passenger compartment interface. The crew/passenger

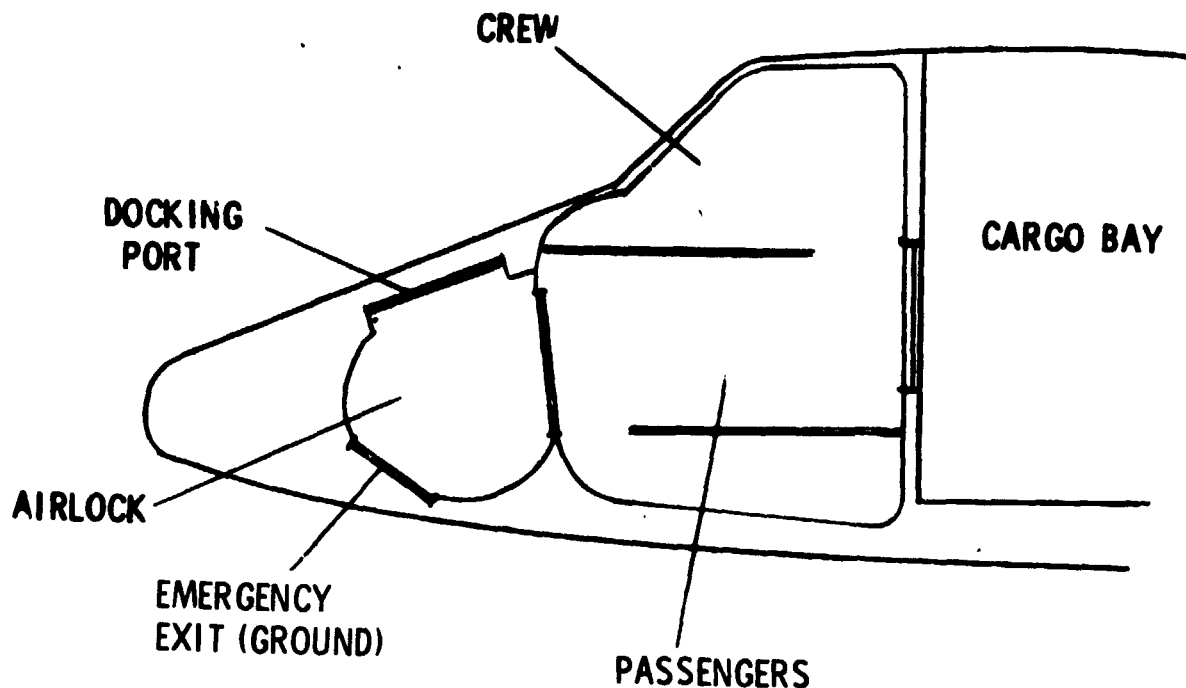


Figure 4.2-1. Baseline Orbiter Configuration

compartment is a single pressure volume but is separated, area wise, into a crew and a passenger compartment by a floor, in which a door is fitted for access between the compartments. Subsystems equipment is housed in under a second floor in the passenger compartment. Because this configuration is baseline for the current shuttle studies, it is given particular emphasis in this task, and is used as a basis from which six other selected candidate configuration concepts are developed.

The selected configurations are based on the number of practical ways in which the following compartments can be arranged:

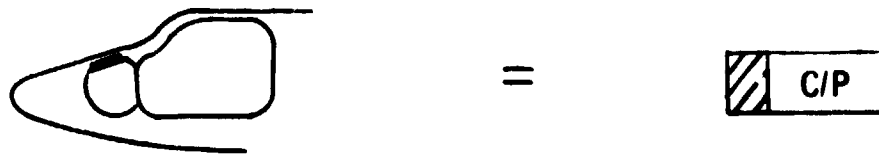
1. Crew compartment
2. Passenger compartment
3. Airlock

Compartments which are not inhabitable, such as the cargo bay, are not included.

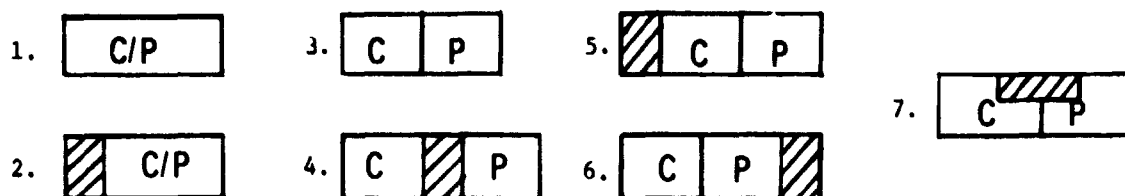
A simplified means was employed for depicting the orbiter compartmentation arrangements, an example of which is illustrated in Figure 4.2-2, together with the seven selected candidate configurations. The baseline orbiter configuration sketch is shown at the upper left corner of the figure. The equivalent compartmentation schematic is shown directly opposite the sketch with the airlock identified with hatched lines.

The location of hatches, doors and openings are outputs of the analysis and therefore are not indicated in the candidate orbiter configurations. From the schematic representations, however, a hatch, door, or opening may be located anywhere there is a solid line.





### CANDIDATE CONFIGURATIONS



C/P CREW/PASSENGER COMPARTMENT  
 C CREW COMPARTMENT  
 P PASSENGER COMPARTMENT  
 AIRLOCK

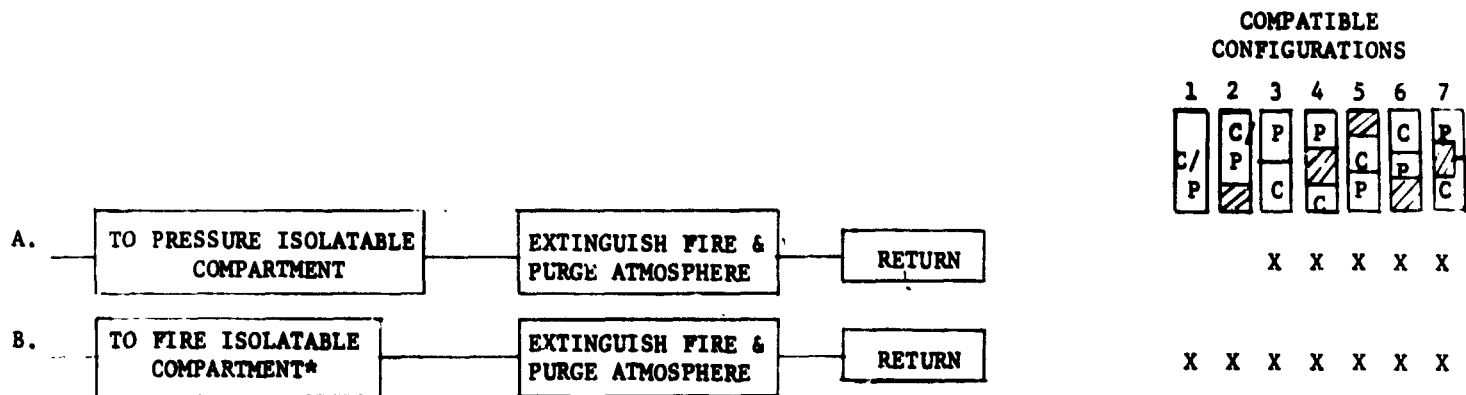
Figure 4.2-2. Candidate Orbiter Configurations

## 4.2.2 Orbiter Compartmentation Analysis

### 4.2.2.1 Operational Options

The operational options available for all emergency situations are shown, together with their applicability to the specific orbiter configurations, in Figures 4.2-3A through Figure 4.2-3G. The single option, which is universally available for all emergencies is to "take the risk". A program decision not to accept the safety recommendations implies that the risk associated with the emergency is being taken.

Within the operational options available to cope with a fire/toxic environment, the requirement to extinguish the fire, purge the atmosphere, and return to the affected compartment is fundamental to all, as shown in Figure 4.2-3A. The underlying rationale for the commonality is that inability to extinguish the fire would be a catastrophe, and the inability to purge the atmosphere and return to the affected compartment would result in loss of the mission. Only the fire isolatable compartment option is compatible with the single compartment configurations. The fire isolatable compartment, as applicable here, means that it is capable of isolating the atmosphere within the compartment from the smoke, fumes, heat, or otherwise toxic environment generated within the affected compartment. The primary means for accomplishing this isolation is envisioned to be through creation of a small positive delta pressure in the isolatable compartment relative to the affected compartment



\* ISOLATES ATMOSPHERE, BUT NO SIGNIFICANT  $\Delta P$  CAPABILITY

Figure 4.2-3A. Options - Fire/Toxic Environment

which could be produced by a slight venting to space capability of the affected compartment. Two areas which affect venting capability are of major concern, however, with this approach. These are the capability to dissipate the generated heat of a fire, and the prevention of excessive pressures due to this heat. An examination, documented in Appendix A, into the heat and pressure produced by a fire within a given volume disclosed that these parameters are far beyond practical structural limits if all the oxygen in a given mixed atmosphere volume, approximating that of a sortie module, is used to support combustion of an unlimited quantity of combustible material. The amount of combustible materials, in terms of total Btu's, within a pressurized volume should, therefore, be controlled within predetermined acceptable limits.

An explosion has but one option as indicated in Figure 4.2-3B, for the single compartment configuration; to rescue the injured, deal with other effects which can be any of the other credible emergencies, and to abort. With two compartment configurations, the injured can be evacuated to the second compartment, and a decision made as to whether to return or abort.

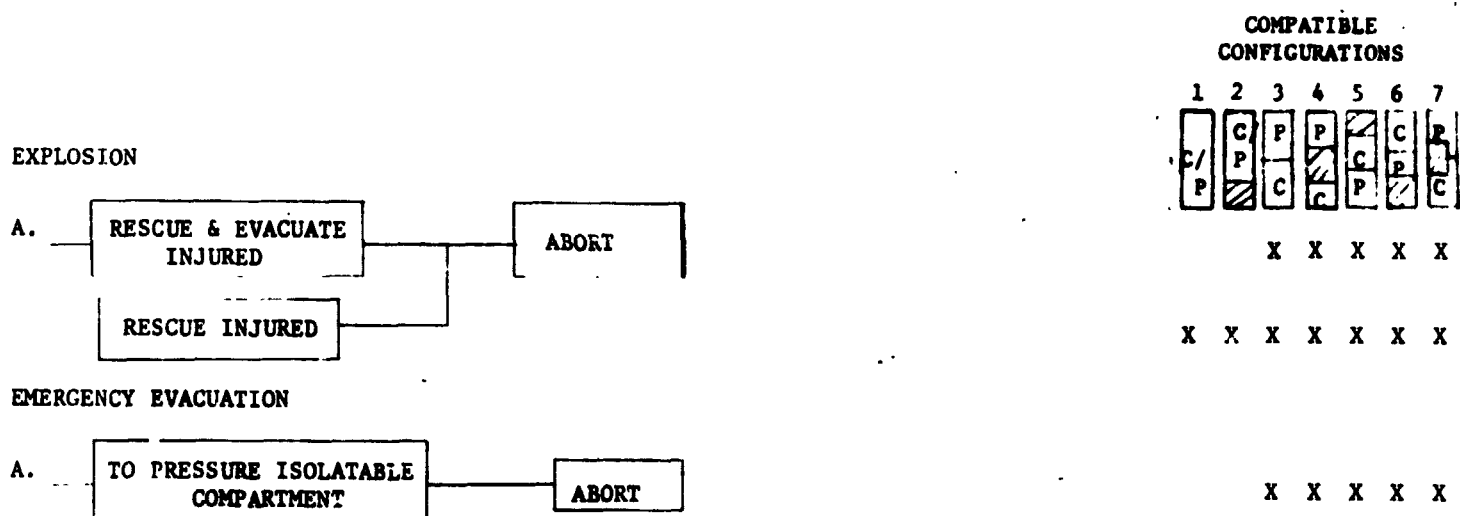


Figure 4.2-3B. Options - Explosion and Emergency Evacuation



Emergency evacuation to a pressure isolatable compartment is required to cope with situations which may require evacuation of a compartment in order to safeguard personnel from risks of an impending emergency. This option is not compatible with the single compartment configurations, therefore, the risk of this emergency occurring must be taken for these configurations.

The options available to cope with loss of pressure are many and complex, as can be seen from Figure 4.2-3C. All options, however, employ one or more of the same basic parameters; suits for crew, suits for crew and passengers, passenger abort in crew compartment, or passenger abort in passenger compartment. Sufficient time is available (2-8 minutes) to evacuate the depressurized compartment, and seek refuge in an adjoining compartment in a shirtsleeve environment. It is also assumed that the crew in all cases must ultimately return to the crew compartment to effect an abort. The options are segregated, for each configuration, into those which are applicable to a depressurized crew compartment and those which apply to a depressurized passenger compartment. Configuration airlocks are assumed to be 2-man airlocks and are used only as an airlock to transfer the crew IVA from a pressurized passenger compartment to a depressurized crew compartment.

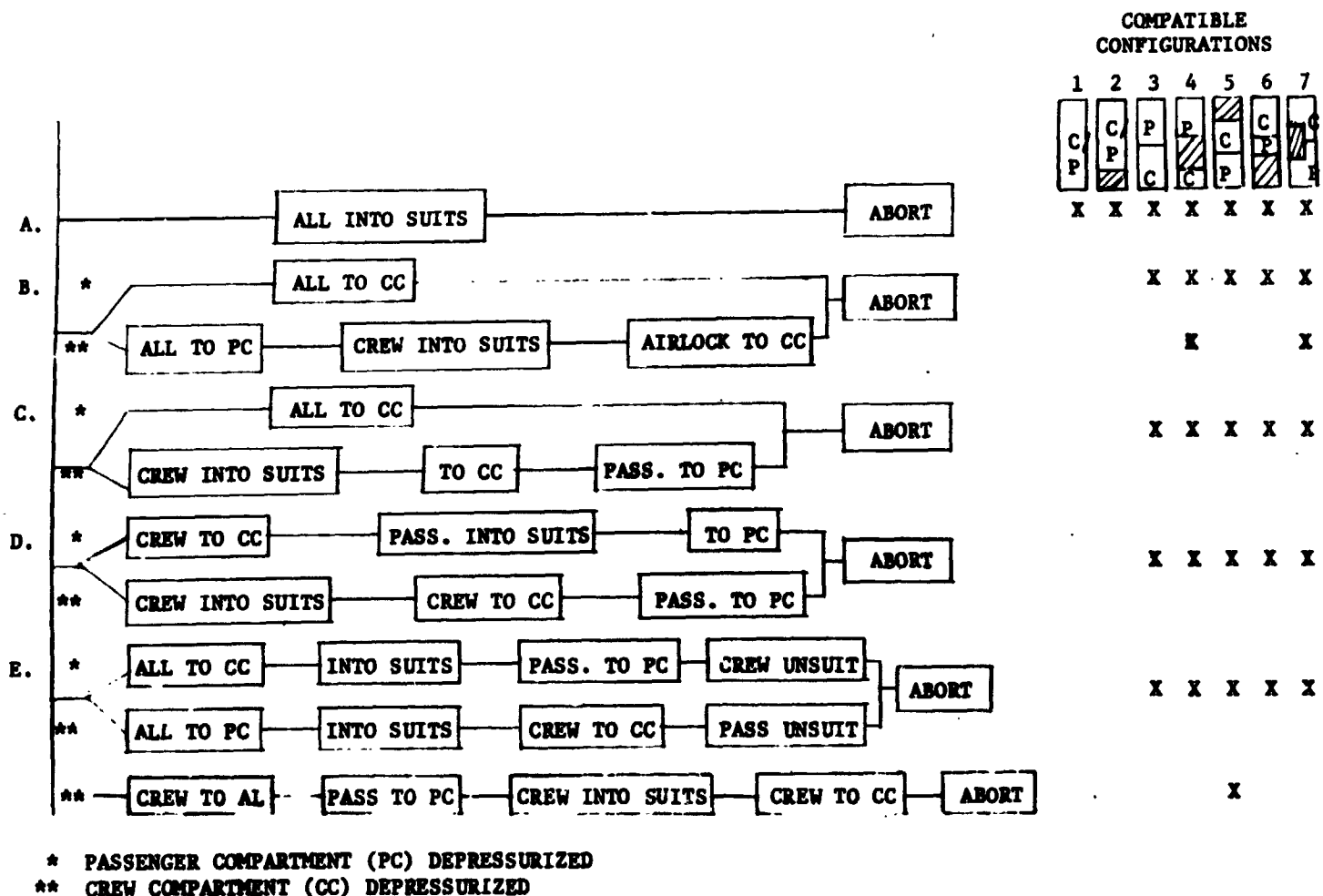


Figure 4.2-3C. Options - Loss of Pressure

With reference to Figure 4.2-3D, inability to close an external hatch upon return from EVA is assumed to be associated only with two compartment orbiter configurations or a single compartment configuration with an airlock. The premise for this assumption is that this emergency can only occur during planned EVA and that it is not reasonable from a safety point of view to plan EVA from a single compartment orbiter configuration which would require all personnel to don suits. It is assumed that, for a single compartment orbiter, a portable airlock would be carried in the cargo bay for missions in which EVA was planned. Planned EVA from the viable configurations can be performed either from an airlock or from the crew or passenger compartments. However, for those configurations which have an airlock, planned EVA is assumed to originate from the airlock. Two fundamental options are available to cope with the failure to close the EVA hatch. One option is to close redundant airlock hatches which are in series, and the other is to re-enter the vehicle via an alternate compartment. While use of redundant hatches does not lead to a requirement for "suits for all" for any configuration, re-entry into the vehicle via an alternate compartment does require "suits for all" for the "single compartment with airlock" and "dual compartment" configurations. For the configuration in which the crew and passenger compartments are separated by an airlock, a unique situation is presented in that during EVA the airlock, the crew and passenger compartments are isolated from one another. A hatch failure at this time would require entry into either the passenger or crew compartments, each of which is adjacent to the airlock. If all passengers are required to be in the passenger compartment during EVA, then the most viable option is to enter via the crew compartment. This option requires only suits for the two crewmen.

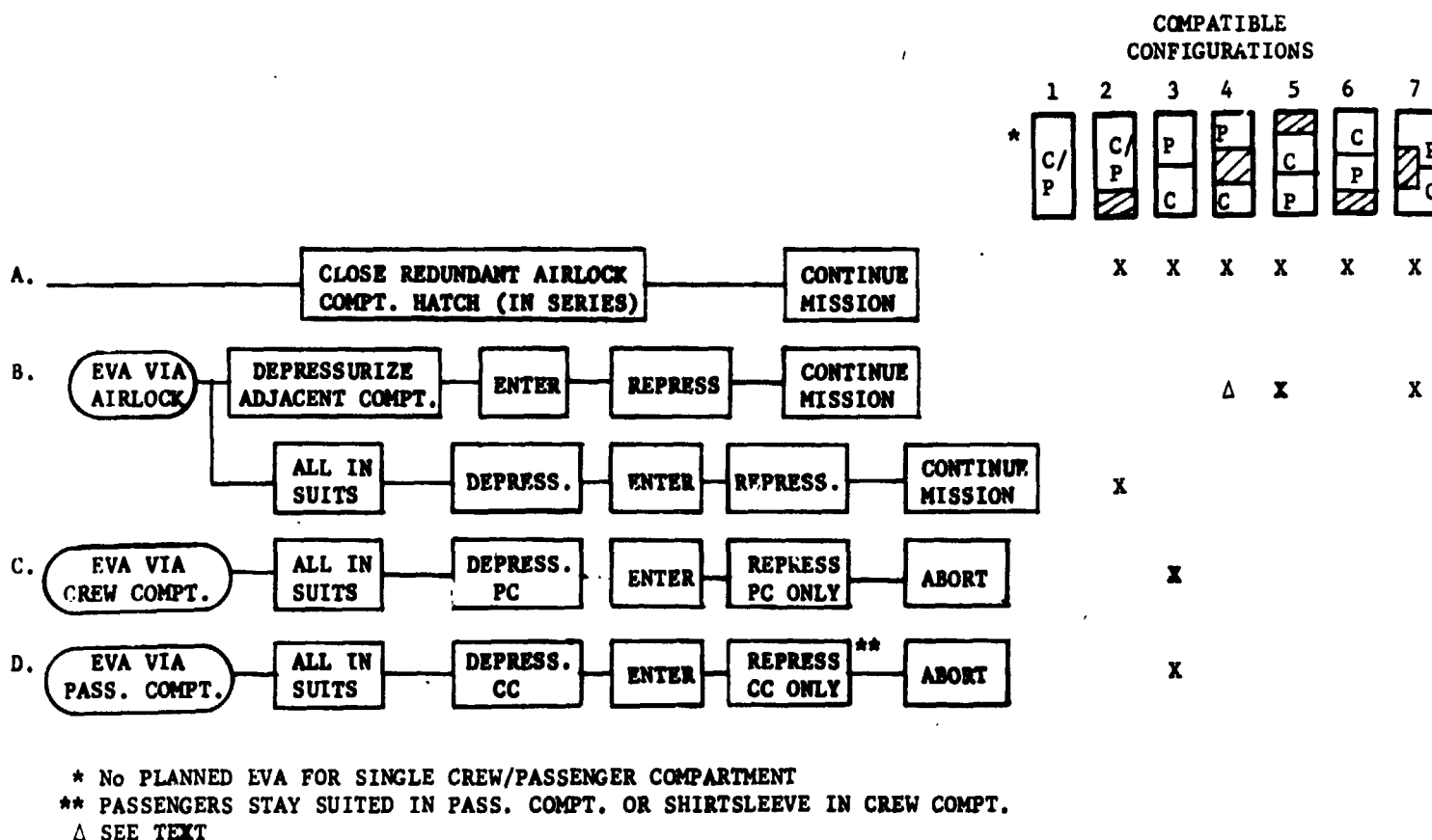


Figure 4.2-3D. Options - Failure to Close External Airlock Hatch When Returning From EVA (Resulting in Inability to Return From EVA)

Complex options are not identified where simple solutions, inherently available in the configuration, are available. For example, the "all in suits" option is not shown as being compatible with the two compartment with airlock configurations for "EVA via airlock" because a simpler solution, requiring depressurization of an adjacent compartment, is available which does not require suits.

Inability to open an internal EVA hatch (reference Figure 4.2-3E) to gain entry into the vehicle after EVA is an emergency which is not applicable to the single compartment configuration for the same reasons as previously discussed for the inability to open an external EVA hatch. In this emergency, the crewmen returning from EVA has the capability to enter the airlock, close the external EVA hatch, and pressurize the airlock to enable coping with the situation in a shirtsleeve environment via a redundant opening mechanism, or by use of a second ingress/egress hatch in the airlock compartment. A third option, available only to two compartments with airlock configurations, requires evacuation of one of the two compartments to enable entry by EVA into the evacuated compartment.

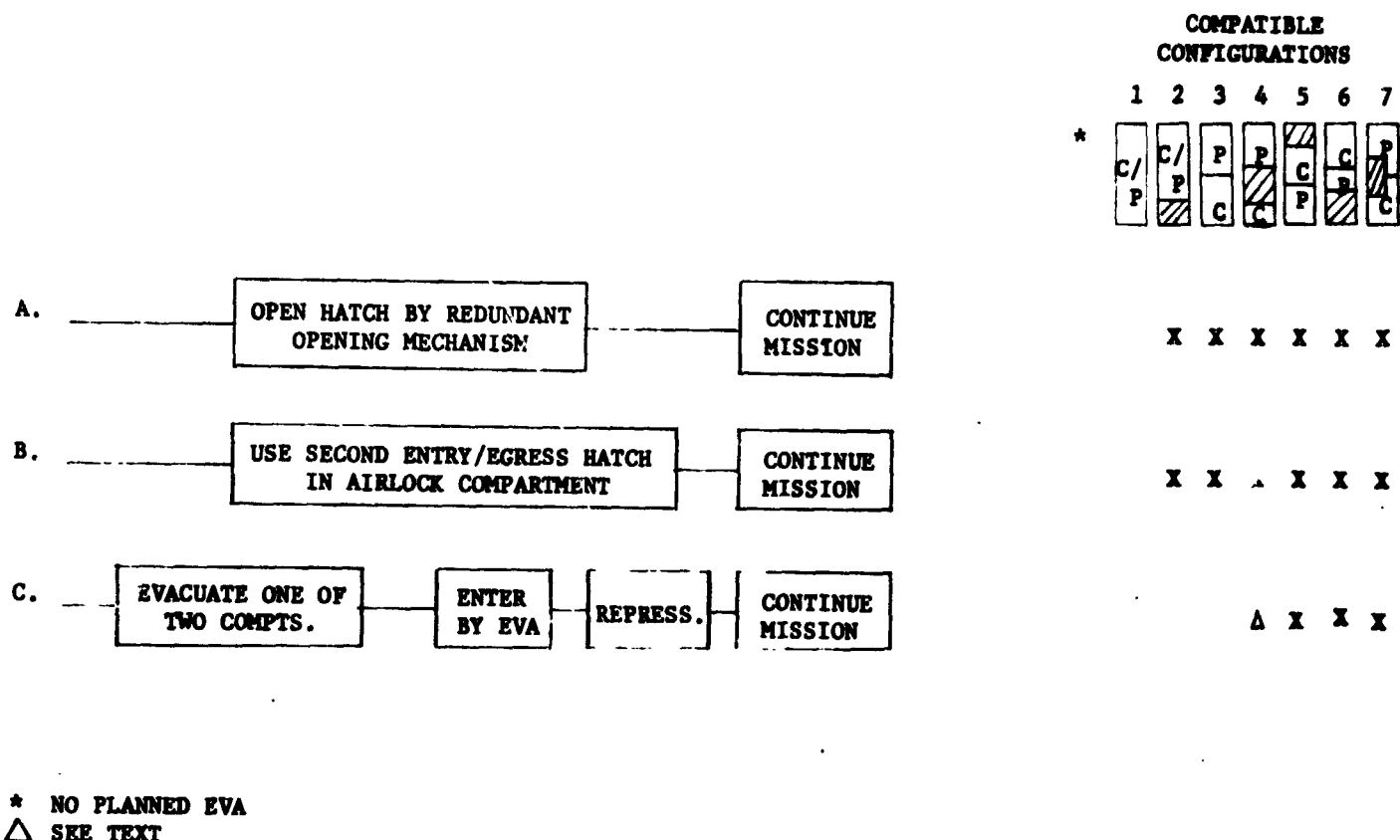


Figure 4.2-3E. Options - Failure to Open Internal Airlock Hatch When Returning From EVA (Resulting in Inability to Return From EVA)

Many dockings with manned and unmanned orbital elements are planned for the orbiter. These dockings can present a unique safety situation if the docking hatch on the orbiter cannot be closed to permit undocking and separation from the docked vehicle. The options developed to cope with this situation (reference Figure 4.2-3F) consider that the docking port with docking hatch can be located on the airlock, crew compartment, passenger compartment, or the integral crew/passenger compartment. Only one option, to provide a redundant docking hatch in series, is compatible with all orbiter configurations. This option is also the only alternative which provides for continuation of the mission for all configurations. A docking port/hatch on the airlock also enables continuation of the mission for all airlock configurations except the configuration in which the passenger and crew compartments are separated by the airlock. Mission abort would be required for this configuration because the de-pressurized airlock would separate the crew and passenger compartments. Placement of the docking port/hatch on an airlock or on the passenger compartment are the only options available which permit coping with this situation in a shirtsleeve environment, and as such do not introduce a requirement for suits for crew or passengers.

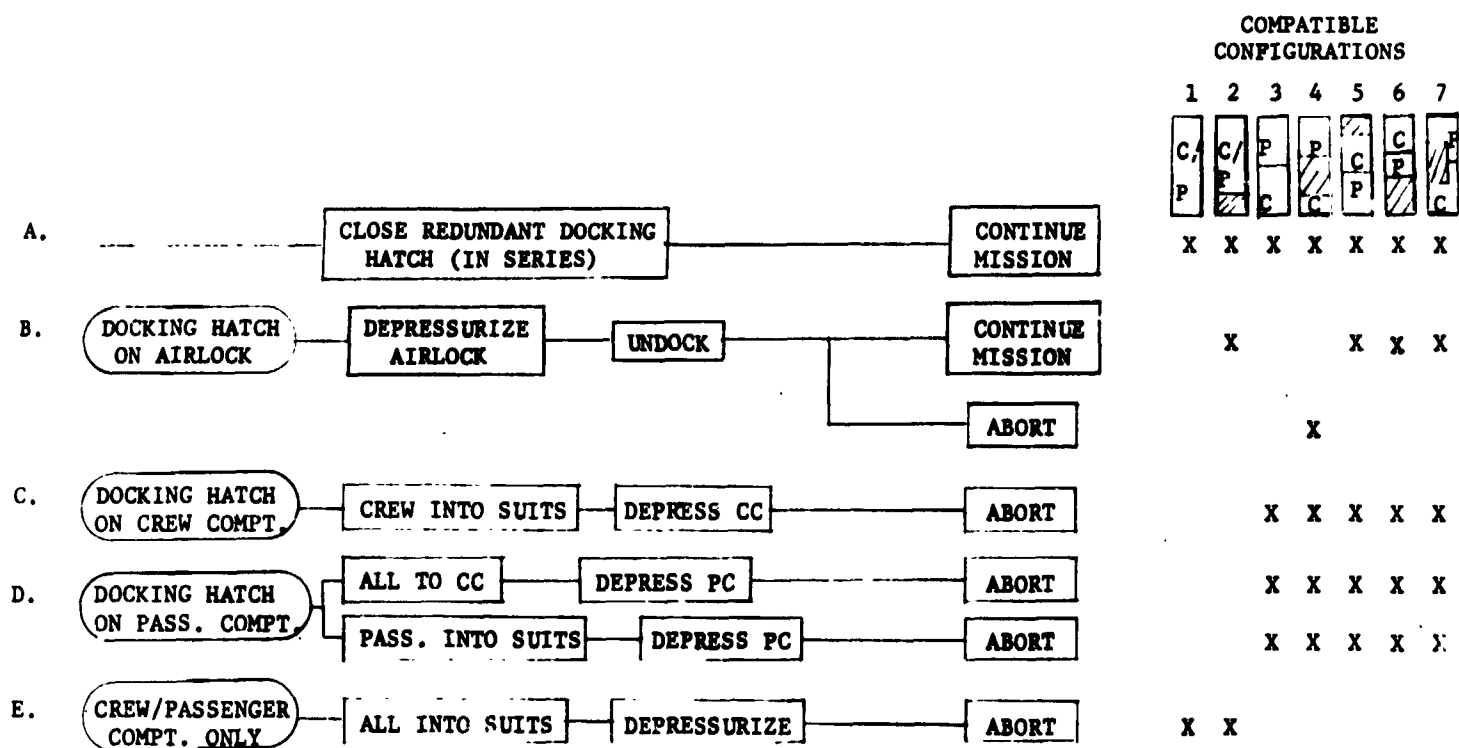


Figure 4.2-3F. Options - Failure to Close Docking Hatch Before Undocking (Resulting in Inability to Undock)

Emergency EVA may be required to perform a visual inspection of external structures, subsystems, or equipment, or otherwise to ascertain and/or effect the best course of corrective action available to cope with certain emergency situations.

An example of such an emergency situation would be where a module, docked to an airlock equipped with an EVA ingress/egress hatch on the docking port, cannot be undocked and is blocking EVA egress for investigation and corrective action.

The options available to cope with the situation of inability to open an EVA hatch when emergency EVA is required are shown in Figure 4.2-3G and encompass alternatives of suits for all, a backup EVA hatch in the compartment used for EVA, or use of one of two compartments as a backup EVA airlock in two compartment/airlock configurations.

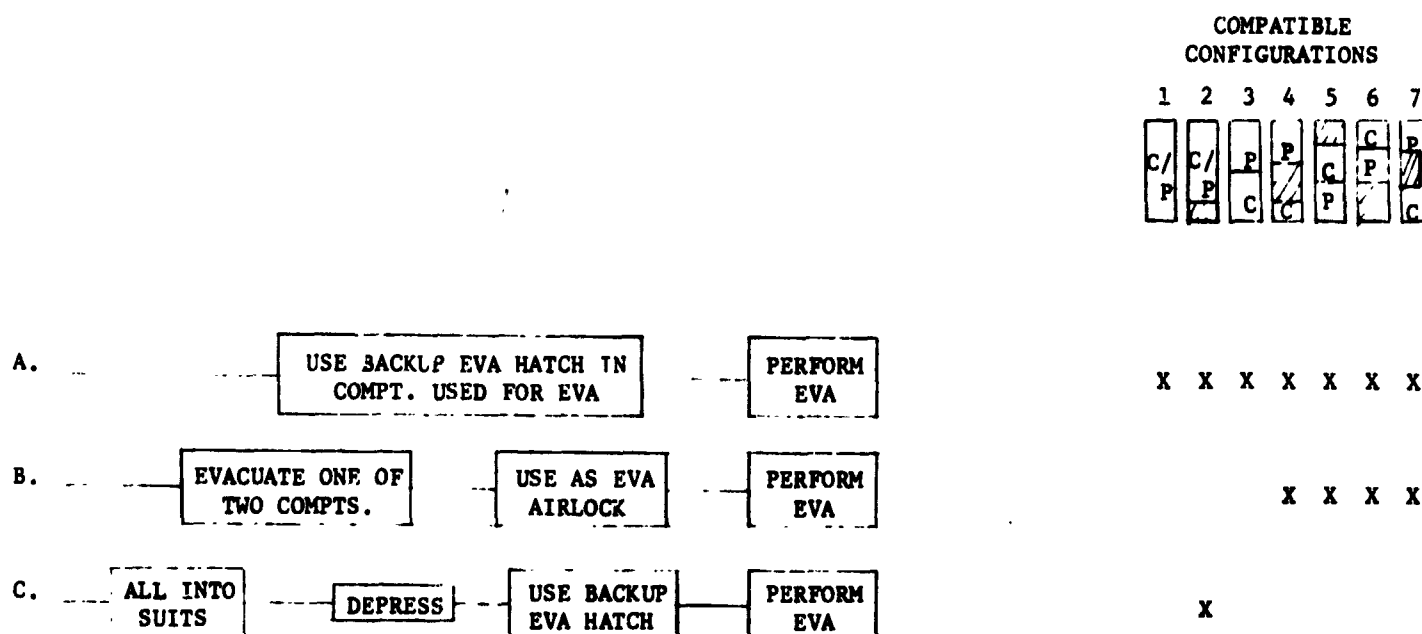


Figure 4.2-3G. Options - Inability to Use Docking Hatch for EVA When EVA Required (Because of Obstruction, When Emergency EVA Required)

The basic requirement, however, originating from this emergency, and inherent in all options is that two EVA ingress/egress paths are required.



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#### 4.2.2.2 Major Safety Requirements

The multitude of options available to cope with each emergency lead to different sets of requirements for each compatible orbiter configuration. These requirements are identified, correlated to the originating emergency, and grouped in accordance with their applicability to each orbiter configuration. A logical reduction of the grouped requirements is made to arrive at a recommended minimum acceptable set for the configuration. This process is illustrated and documented in Figures 4.2-4A through 4.2-4D.

Hatch requirements are an important consideration but are not major configuration drivers and, therefore, all hatch requirements relative to the parameters of location, dual opening (hatch within a hatch) or dual closing (back to back) are consolidated under the column titled "Hatch Requirements". Reference is made to the previous options section for detailed hatch requirements.

These charts contain sufficient information to ascertain the impact on vehicle configuration of the elimination of one or more requirement options. If, for example, eight psi suits were eliminated as a viable requirement option on the two compartment with airlock orbiter configurations due to a programmatic decision, the remaining viable alternatives could readily be determined, as shown by Figure 4.2-4E. The remaining viable alternatives encompass suits for all, capability to perform an abort in a vacuum environment, passenger abort in suits, and passenger abort in the crew compartment. The viable requirement sets resulting are suits for all (3.5 psi) with passenger abort in suits, or shirtsleeve passenger abort in the crew compartment. The capability to perform an abort in a vacuum is common to both sets of requirements. From the safety point of view the latter alternative in which the passengers are aborted in a shirtsleeve environment is preferred.

A summary of the recommended requirements for all seven candidate orbiter configurations is shown in Figure 4.2-5. Only one configuration, the two compartment with an airlock in between, is identified as not acceptable because a problem in the airlock can isolate the passengers from the crew compartment.

Five basic options were identified for comparing the configurations to arrive at relative safety ratings. These relate to the number and type of suits; whether IVA or EVA is required to effect transfer of personnel to the crew compartment in the event of an emergency; and whether a refuge compartment is available. These five options are:





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Emergency/ Failure	Fire Isol. Comp. Suits for All	8 Psi Suits Crew	Pass.	Abort in Vacuum	Pass. Abort in Crew Comp.	Hatch Reqs. *
Fire/Toxic Environment	X					
Explosion						
Emergency Evacuation		--	RISK	--		
Loss of Pressure		X	X	X	X	
Fail to Close External EVA Hatch		--	N/A	--		
Fail to Open Internal EVA Hatch		--	N/A	--		
Fail to Close Docking Hatch for Undocking		X				X
Inability to Use Docking Hatch for EVA when EVA Required						X
RECOMMENDED	X	X	X	X	X	X

CONFIGURATION

1.

C / P

or

X = Requirement  
\* Redundant Opening, Closing; Location

Figure 4.2-4A. Major Safety Requirements, Crew/Passenger Compartment Only

Emergency/ Failure	Fire Isol. Comp. Suits for All	8 Psi Suits Crew	Pass.	Abort in Vacuum	Pass. Abort in Crew Comp.	Hatch Reqs. *
Fire/Toxic Environment	X					
Explosion						
Emergency Evacuation		--	RISK	--		
Loss of Pressure		X	X	X	X	
Fail to Close External EVA Hatch		X				X
Fail to Open Internal EVA Hatch						X
Fail to Close Docking Hatch for Undocking		X	X	X		X
Inability to Use Docking Hatch for EVA when EVA Required		X				X
RECOMMENDED	X	X	X	X	X	X

CONFIGURATION

2.

AL [ C / P ]

or

or

or

X = Requirement  
\* Redundant Opening, Closing; Location

Figure 4.2-4B. Major Safety Requirements, Crew/Passenger Compartment  
With Airlock Only



Emergency/ Failure	Fire Isol. Comp.	Suits for All	8 per Suits	Crew	Pass.	Abort in Vacuum	Pass. Abort in Crew Comp.	Hatch Reqs *	
Fire/Toxic Environment									Evacuate to Adjacent Compartment
Explosion									
Emergency Evacuation									
Loss of Pressure	X	X	X	X		X			or
	X	X	X	X		X			
	X		X	X					
Fail to Close External EVA Hatch	X		X				X		3. or
	X			X					
Fail to Open Internal EVA Hatch							X		
Fail to Close Docking Hatch for Undocking	X			X		X	X		or
			X						
Inability to Use Docking Hatch for EVA when EVA Required							X		
RECOMMENDED	X	X	X	X		X	X		or
			X	X			X		

X = Requirement  
\* Redundant Opening, Closing; Location

Figure 4.2-4C. Major Safety Requirements, Separate Crew and Passenger Compartments

Emergency/ Failure	Fire Isol. Comp.	Suits for All	8 per Suits	Crew	Pass.	Abort in Vacuum	Pass. Abort in Crew Comp.	Hatch Reqs *				
Fire/Toxic Environment									Evacuate to Adjacent Compartment			
Explosion												
Emergency Evacuation												
Loss of Pressure	X	X	X	X		X	4,5,7		or			
	X	X	X	X		X						
Fail to Close External EVA Hatch							X		6. <table border="1"><tr><td>C</td><td>P</td><td>AL</td></tr></table>	C	P	AL
C	P	AL										
Fail to Open Internal EVA Hatch							X		7. <table border="1"><tr><td>C</td><td>AL</td><td>P</td></tr></table>	C	AL	P
C	AL	P										
Fail to Close Docking Hatch for Undocking	X		X	X		X	X		or			
			X						5. <table border="1"><tr><td>AL</td><td>C</td><td>P</td></tr></table>	AL	C	P
AL	C	P										
Inability to Use Docking Hatch for EVA when EVA Required							X		4. <table border="1"><tr><td>C</td><td>AL</td><td>P</td></tr></table>	C	AL	P
C	AL	P										
RECOMMENDED	-- SEE FOLLOWING CHARTS --											

X = Requirement  
\* Redundant Opening, Closing; Location

Figure 4.2-4D. Major Safety Requirements, Separate Crew, Passenger and Airlock Compartments

Emergency/ Failure	Fire Isol. Comp.		Suits for All		8 psi Suits		Abort in Vacuum		Pass. Abort in Crew Comp.		Hatch Regate *	
					Crew	Pass.						
Fire/Toxic Environment												Evacuate to Adjacent Compartment
Explosion												
Emergency Evacuation												
Loss of Pressure		X			X	X		X	4,5,			or
Fail to Close External EVA Hatch									X			
Fail to Open Internal EVA Hatch									X			
Fail to Close Docking Hatch for Undocking		X			X	X		X	X			or
Inability to Use Docking Hatch for EVA when EVA Required									X			
VIALE REQUIREMENTS SETS		X			X	X		X	X	X		or
RECOMMENDED					X			X	X	X		

Figure 4.2-4E. Effect of Eliminating 8 psi Suits  
(Reference Figure 4.2-4D)

Configuration	Fire Isol. Comp.		Suits for All		8 psi Suits		Abort in Vacuum		Pass. Abort in Crew Comp.		Hatch Regate *	
					Crew	Pass.						
C / P	X	X	X	X	X						X	
C / P	X	X	X	X	X						X	
C P		X		X	X	X		X	X	X		or
C P		X		X	X	X		X	X	X		or
C P		X		X	X	X		X	X	X		or
C P					X			X	X	X		
C P												
C P												
NOT RECOMMENDED												

Figure 4.2-5. Summary of Recommended Requirements




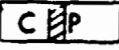



<u>Option</u>	<u>Pressure Suits</u>		<u>Transfer Mode to Crew Compartment</u>	<u>Refuge Compartment Available</u>
	<u>Quantity</u>	<u>Type</u>		
A	All	8 psi	N/A	No
B	2	8 "	N/A	Yes
C	All	3.5 "	IVA	Yes
D	2	3.5 "	IVA	Yes
E	2	3.5 "	EVA	Yes

A comparison of the configurations, using these options, as primary parameters, is shown in Figure 4.2-6. An additional parameter, that of reaction time, is introduced to signify the amount of time available to react to the credible emergencies. Seven (7) minutes corresponds to the time required for obtaining access to and donning 8 psi suits. Two (2) minutes is that time required for personnel to evacuate, in a shirtsleeve environment, an affected compartment and seek refuge in the adjoining compartment.

The safety ratings as listed are based on the reaction time and availability of a rescue compartment. Options which result in minimum reaction time and exhibit a rescue compartment are most favorable. The acceptable, good, and best ratings apply to the combination of a particular configuration and the number and type of pressure suits carried on-board. The ratings are based on the resulting capabilities of the configuration/suit combinations, as follows:

<u>Reaction Time</u>	<u>Safety Factor</u>		<u>Safety Rating</u>
	<u>Refuge Compartment</u>		
7 mins	No		Acceptable
7 mins	Yes		Good
2 mins	Yes		Best

The acceptable and good ratings are applicable to Options A and B and are distinguished by the availability of a refuge compartment. Configurations for which the acceptable rating applies (therefore, Configurations 1 and 2 - Option A) do not have a refuge volume and, therefore, require a minimum of 7 minutes of reaction time for all personnel to locate and don 8 psi suits. If, however, a refuge volume is available as is required by Option B, passengers may egress to it and be afforded a safe haven within 2 minutes. Therefore, since an additional margin of safety is provided by Option B over Option A, Option B is given a "good" rating.

CONFIGURATION	OPTION	PRESSURE SUITS		SAFETY FACTORS		SAFETY RATING
		QTY.	TYPE	REACTION TIME*	REFUGE COMPT.	
1. 	A	ALL	8 PSI	7 MINS	NO	ACCEPTABLE
2. 	A	ALL	8 PSI	7 MINS	NO	ACCEPTABLE
3. 	B	2	8 PSI	7 MINS	YES	GOOD
	C	ALL	3.5 PSI	2 MINS	YES	BEST
4. 	D	2	3.5 PSI	2 MINS	YES, IF ACCESSIBLE	POOR **
5. 	B	2	8 PSI	7 MINS	YES	GOOD
	C	ALL	3.5 PSI	2 MINS	YES	BEST
	D	2	3.5 PSI	2 MINS	YES	BEST
6. 	B	2	8 PSI	7 MINS	YES	GOOD
	C	ALL	3.5 PSI	2 MINS	YES	BEST
	E	2	3.5 PSI (EVA)	2 MINS	YES	BEST
7. 	D	2	3.5 PSI	2 MINS	YES	BEST

\* REACTION TIME TO ACHIEVE SAFETY: 7 MINS TO DON SUITS; 2 MINS TO EGRESS TO REFUGE COMPT  
 \*\*AIRLOCK PROBLEM CAN PREVENT ACCESS TO CREW COMPARTMENT

Figure 4.2-6. Comparison of Configurations

Only one configuration, that which was not previously recommended, is rated as poor. This configuration, in which the crew and passenger compartments are separated by an airlock, can result in isolation of the crew and passenger compartments if an airlock problem is encountered.

#### 4.2.3 Conclusions and Recommendations for Baseline Orbiter Configuration

The safety conclusions and recommendations for the baseline orbiter configuration (Figure 4.2-1) involve compartmentation, suit provisions, airlock sizing, EVA ingress/egress, and operational and subsystems capability. These are:

- Quick-donning pressure suits which do not require prebreathing (8 psi suits) should be provided for all on-board personnel.



- The crew/passenger compartment should be divided into two sections by a partition which can exclude smoke and fumes, and can provide protection against excessive heat from a fire. Pressure build-up beyond the capability of the partition can be provided by suitable pressure relief valves in each section. These sections can provide temporary refuge until corrective measures can be taken.
- All equipment required for return to earth should be capable of operating in a depressurized environment, and of being operated by the crew in pressure suits.
- Capability should be provided for returning from EVA directly into the crew/passenger compartment.
- Provided the above recommendations are implemented, the airlock is not required for safety purposes. It should be available, possibly as a payload item, or missions for which EVA is planned.
- If the airlock is capable of accommodating all passengers in emergency shirtsleeve conditions through deorbit and entry, then 8 psi suits are required only for the orbiter crew on those missions. The passengers have time to return to their seats for landing after reaching low altitudes.

#### 4.2.4 Configuration With Large Airlock

The airlock requirements for performing EVA are that the airlock be sized to accommodate 2 men in pressure suits with portable life support systems (PLSS). Such an airlock is likely to be large enough to accommodate 4 and possibly 6 men in shirtsleeves.

The airlock for the baseline orbiter which resulted from the Phase B study is even larger than this requirement. It is a sphere of 2.4 m (8 ft) diameter, intercepted by the flat hatches. As shown in Figure 4.2-7, this airlock can accommodate at least eight men in hammock type of supports under emergency shirtsleeve conditions. Enough room is available for four more men, if desired, making a total of 12 men in the airlock.

Such a large airlock can be used as a second compartment in the event of an emergency. In addition to being sized for two crewmen with PLSS, it must be capable, in an emergency, of supporting all passengers in a shirtsleeve environment through deorbit and reentry. This may require in excess of six hours life support capability in the airlock for return to CONUS (Continental U.S.A.) landing sites. The capability to land with the passengers in the airlock is not required because the passengers can return to the crew/passenger compartment to their respective (or makeshift) landing positions after the orbiter re-enters the sensible atmosphere and the cable is repressurized to a habitable environment. Passenger egress from the airlock could occur at approximately 4500 m (15,000 ft) altitude, 4 minutes prior to landing. Specially sized inward bleed valves on the crew/passenger compartment are required to ensure an adequate repressurization rate.

Two pressure suits only are required in this case, for use by the crewmen. These must be quick-donning 8 psi suits, which do not require any pre-breathing. The airlock cannot be used for getting into the suits, as the airlock hatch cannot be opened when shirtsleeve passengers are inside it and the atmosphere in the orbiter has been lost or contaminated. The two suits should therefore be kept in the crew/passenger compartment, not the airlock.

It is estimated that the time required to don the suits is 7 minutes, or equivalent to the time available in a shirtsleeve environment to cope with pressure loss through a one-inch diameter hole. Additional reaction time can be gained by employing flood flow control, which replaces the atmosphere at approximately the same rate at which it is being lost, to maintain the atmosphere at the minimum acceptable pressure level.

An operational option which is available with this configuration, but which is not recommended as the normal emergency procedure, is for all personnel, including the two crewmen, to evacuate to the airlock. Flood flow control is then don their suits in the airlock. Flood flow control is then employed to repressurize the crew/passenger compartment, which may have been totally evacuated to space, to at least 8 psi. After equalizing the airlock pressure to that of the crew/passenger compartment, the crew egresses and either repairs the leak or performs an abort. This option allows the crew a significantly greater amount of time to don their suits, but involves a time-critical operation in opening and closing the hatch. It also permits rescue of all personnel by means of a rescue orbiter (if available) docked to the airlock, if the leak in the crew/passenger compartment exceeds flood flow capability. Parametric charts involving flood flow capability are included in the appendix of this report.



**Figure 4.2-7. Emergency Accommodations in Baseline Orbiter**



For missions in which EVA is planned as part of the normal mission, pressure suits must be carried for all the passengers, as well as for the two crewmen and the EVA men. These are required in case an airlock malfunction does not allow repressurization of the airlock (e.g., the external hatch cannot be sealed). The crew and passengers then don their suits, the crew/passenger compartment is then depressurized, and the EVA men can enter. These additional suits may be much simpler than EVA or IVA suits, as no activities are to be performed in them. If the EVA men plan to red-line their oxygen supply to maintain a few hours reserves by the time they return, these additional suits can be 3.5 psi suits which require perhaps two hours of pre-breathing before reducing to the operating pressures. Otherwise, they should be 8 psi suits.

#### 4.2.5 Alternative Orbiter Configuration

An alternative safety approach for the orbiter is shown in Figure 4.2-8. This configuration is similar to the baseline with the exception that the forward located airlock is eliminated with its volume being absorbed into a single habitable compartment; and special design requirements are imposed to use the floor of the crew compartment to deal with a fire or atmospheric contamination.

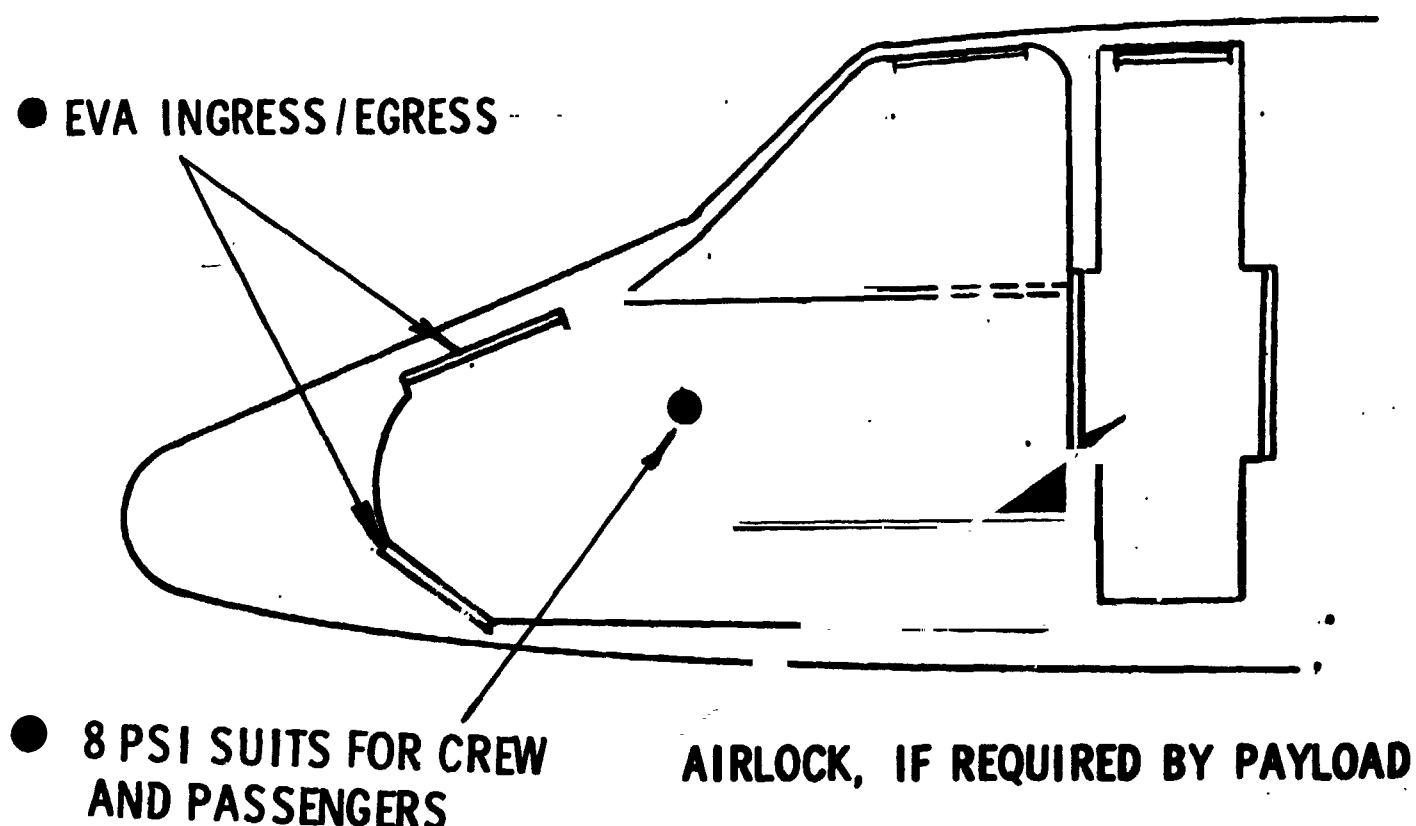


Figure 4.2-8. Alternative Safety Approach for Orbiter



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The recommended approach for coping with a fire/toxic environment for this configuration is considerably different from that recommended for the preferred configuration. In order to isolate the crew/passengers from a fire/toxic environment in the passenger area, all personnel must egress to the crew area where they are afforded protection by smoke-tight floors and doors, and a slightly greater pressure in the crew area with respect to the passenger area. Sufficient venting must be provided in the passenger area to limit excess temperatures and pressures within tolerable bounds.

In the event of a fire/toxic environment in the crew area, the procedure is to evacuate to the passenger area, with the pressure being adjusted to prevent smoke, etc. entering the passenger compartment. Fire-fighting and purging provisions are required in both areas, as for the baseline configuration.

The equipment required for return to earth must be capable of operating and being operated in a depressurized condition, as for the baseline configuration.

Pressure suits (8 psi) must be carried for all on-board personnel for all missions. Loss of pressurization within the compartment requires all personnel to don their suits, which takes approximately 7 minutes, the men helping each other in pairs to don suits. Other recommendations relative to loss of pressure are identical to those previously discussed for the preferred configuration.

A portable airlock can be located in the cargo bay for those missions in which EVA is a planned activity. Since suits are provided for all, however, emergency EVA can still be performed from the crew/passenger compartment.

A redundant EVA hatch is recommended, as in the preferred configuration.

#### 4.2.6 Ideal Orbiter Configuration

An ideal safety configuration is one in which safety is inherent in the configuration, not through subsystems or time-consuming complicated procedures which may integrally involve personnel. The foremost objectives of such a configuration are (1) to de-sensitize the vehicle from the potential effects of credible emergencies, (2) to de-sensitize the vehicle from arbitrary criteria, such as vent valve sizing, factored into subsystems design resulting from a theoretical analysis of the credible emergencies, (3) to minimize the time required to safeguard personnel, and (4) to maximize the time available to perform corrective action.

One configuration which ideally satisfies these objectives relative to the credible emergencies and effects considered in this task, is shown in Figure 4.2-9. The configuration consists of a crew compartment, a passenger compartment, a two-man airlock, a docking port, three internal hatches, and three external hatches, one of which is a docking port hatch. Two 3.5 psi suits are provided for the two crewmen. Requirements include capability for abort with the passenger in the crew compartment, capability for abort equipment to operate in a vacuum, and capability abort controls to be operatable by men in pressure suits.

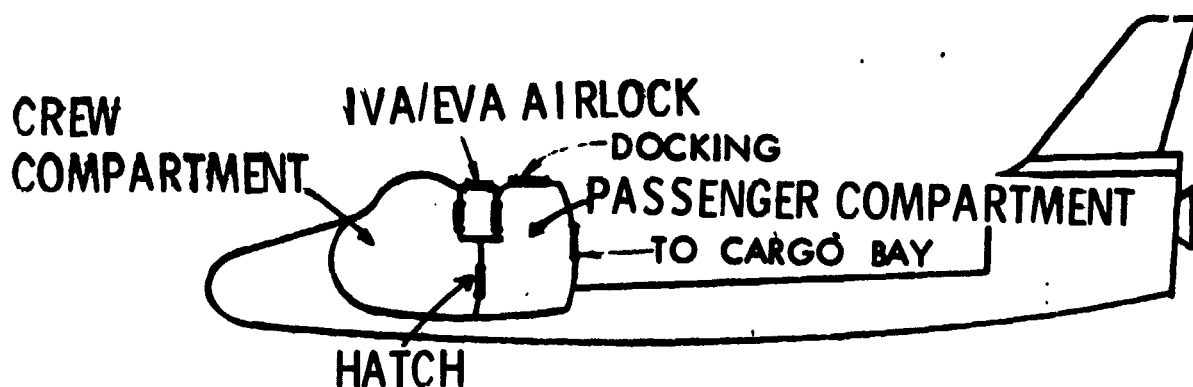


Figure 4.2-9. Ideal Orbiter Safety Configuration

In the event of loss of pressurization in the crew compartment, all personnel would seek refuge via the hatch/opening between the compartments, in the passenger compartment. The two crewmen would then don 3.5 psi suits and return, via IVA through the airlock, to the crew compartment to effect a repair or otherwise perform an abort. Conversely, loss of pressure in the passenger compartment would require all personnel to egress to the crew compartment and abort in this compartment if repairs, via IVA, could not be performed to restore a habitable environment.

The airlock, in addition to providing IVA capability between these compartments, permits emergency EVA to be accomplished while a vehicle is docked to the docking port on the passenger compartment. This emergency EVA capability would also be provided with no change in the capability of the configuration if the docking port and the emergency EVA hatch were interchanged. Emergency controls, including those for extinguishing a fire and for venting to space and re-establishing a habitable environment in either compartment, are located in the airlock.

An emergency in the crew compartment which inhibits return to the compartment or which results in inoperative abort equipment or controls would require abandonment of the vehicle via a rescue vehicle. The rescue vehicle must be capable of rescuing all personnel, or life support, capable to sustaining excess personnel until the next rescue vehicle is available, must be provided in the passenger compartment or delivered by the initial rescue vehicle.



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#### 4.3 SAFETY ANALYSIS OF SORTIE MODULE CONFIGURATIONS

Evaluation of the sortie module configurations is involved with the effects of the sortie module configuration on orbiter personnel and vehicle safety, and conversely with the use of the orbiter as a refuge volume for sortie module personnel.

The sortie module may be unmanned, such as a pallet type, or may be pressurized and habitable. A mission which employs a nonpressurizable, unmanned sortie module requires that the orbiter provide the life support, living quarters, and experiment monitoring facilities for the experimenters. In such a mission, the safety of the experimenters is solely dependent on the orbiter internal configuration, candidates of which have been analyzed in the previous section.

Pressurized, manned sortie modules in which experimenters may spend a majority of their working, leisure, and sleeping time must be capable of coping with the credible emergencies of Section 4.1.

In this respect, the following analysis has been accomplished not only to identify and recommend primary safety requirements for the sortie module, but also to understand the relative sensitivity of the sortie module and orbiter configurations and the shuttle mission to the credible emergencies and the resulting safety requirements.

##### 4.3.1 Candidate Sortie Module Configurations

Among the many mission classes planned for the shuttle are the sortie missions. For these missions, the orbiter will deliver to orbit a sortie module which will house and support specialists for experiments and observations in earth orbit for from 7 to 30 days. The sortie module or re-usable space laboratory, in addition to providing the necessary power supply, experiment racks, and observation ports for experiments, will provide living accommodations and life support functions which are in excess of orbiter capability.

Although the sortie module may eventually be equipped with systems that would permit its separation from the orbiter for independent operations, current studies (reference SOAR and RAM) are constrained to consider only missions in which the sortie module will remain attached to the orbiter. This task considers only manned sortie modules attached to the orbiter.

Two basic sortie module concepts are currently under investigation in the \*RAM study. One concept considers that all experimenter living accommodations, life and subsystems support (in excess of orbiter capability) and experiment functions will be contained within a single payload module. The alternate concept places all experiment functions in one module (RAM-Research Applications Module) and support functions, such as the living accommodations, life and subsystems support, in an adjacent attached module (RSM-RAM Support Module). The latter concept assumes that the Support Module is a general purpose module capable of supporting many different kinds of experiment modules.

\*Research and Applications Module (RAM) Phase B Study - Contract NAS8-27539

These RAM sortie module concepts are shown in Figure 4.3-1 together with the NR baseline deployment concept. Airlock(s) are not shown but may be located anywhere they are required. The sortie RAM or payload module may be unpressurized or may be pressurized and habitable. The RAM Support Module (RSM) is a pressurized, habitable module and as shown in the figure the RSM and sortie RAM are provided with high pressure gas storage bottles around the periphery of the end docking port which interfaces with the orbiter.

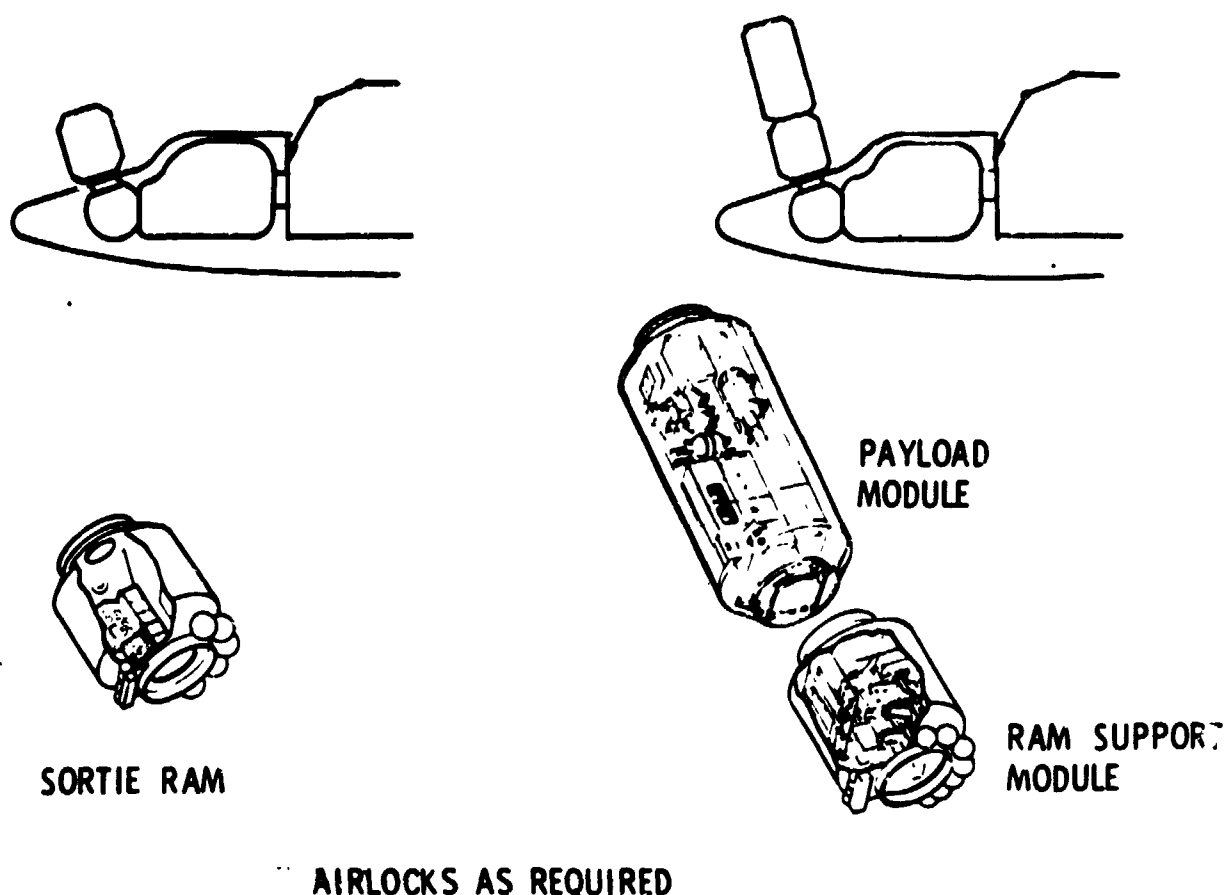


Figure 4.3-1. RAM Sortie Module Concepts

The sortie module configurations selected for evaluation are compatible with and encompass the RAM study concepts. Six candidate configurations, shown in Figure 4.3-2, consider compartmentation arrangements for up to two pressure isolateable volumes, each of which is large enough to accommodate all experimenters in the event of an emergency, and a two-man airlock. An airlock capable of supporting all experimenters simultaneously would be treated as additional volume.

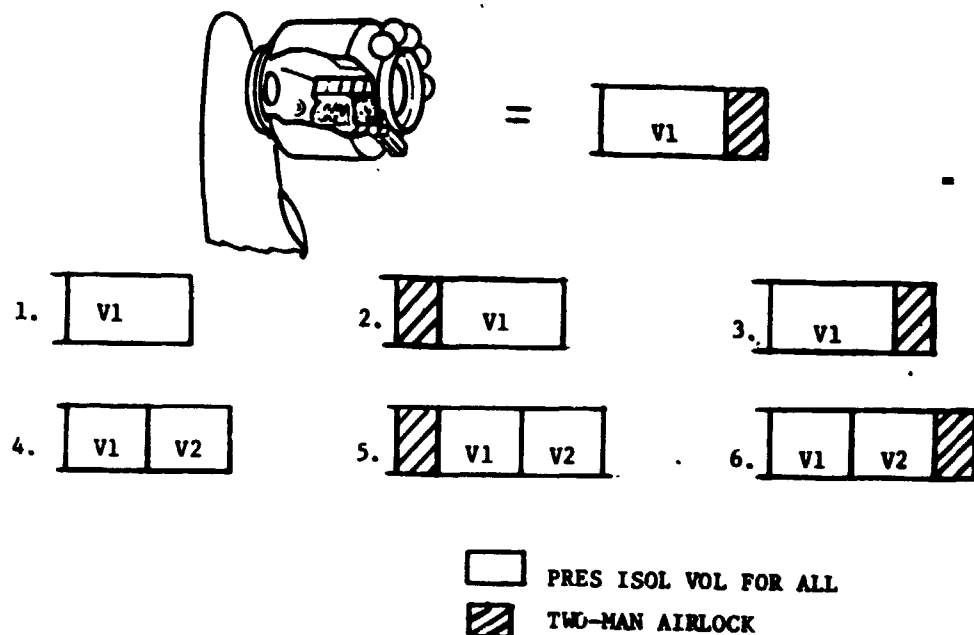


Figure 4.3-2. Candidate Sortie Module Configurations

Numerous operational modes are available, in addition to the NR baseline, for deploying the sortie modules for orbital experiments. Three primary deployment options which include both the single and dual module concepts and encompass the baseline option (Figure 4.3-3) were identified. The first option does not require, for normal experiment operations, any deployment mechanism because the module remains in the same position in the cargo bay throughout the mission. Option 2 requires a rotatable payload handling mechanism (MDAC payload handling concept) as compared to 3, which employs a manipulator. The sortie module outline on Option 3 indicates the position of the sortie module when attached to the docking port of the baseline configuration orbiter.

Several other options were conceived which were not considered seriously because of configurational characteristics which are deemed impractical. These are shown in Figure 4.3-4. Option 1 requires two radial docking ports, one attached near each end of the sortie module. Option 2 requires the use of both the rotatable and manipulator mechanisms. Options 3 and 4 were given consideration in the RAM study but were disqualified as primary deployment schemes.

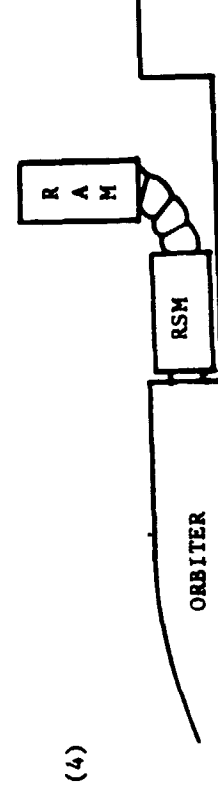
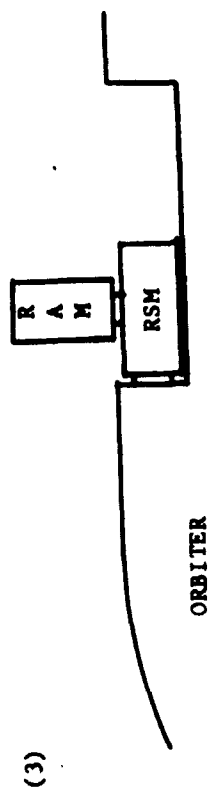
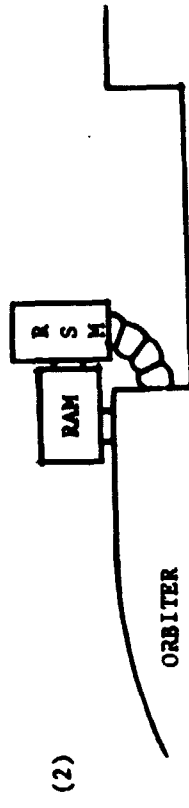
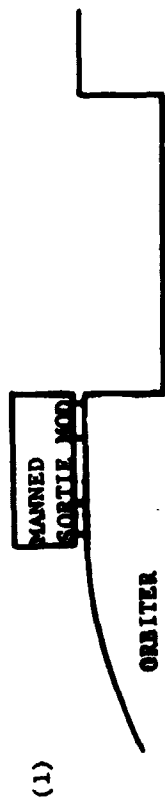


Figure 4.3-4. Secondary Sortie Module Deployment Options

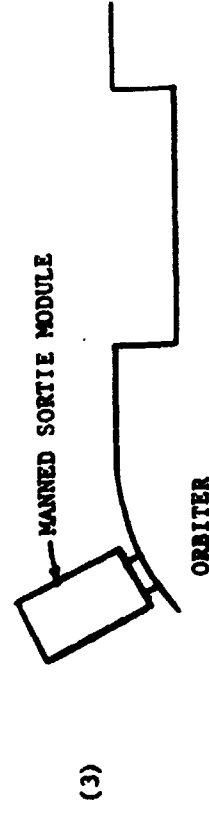
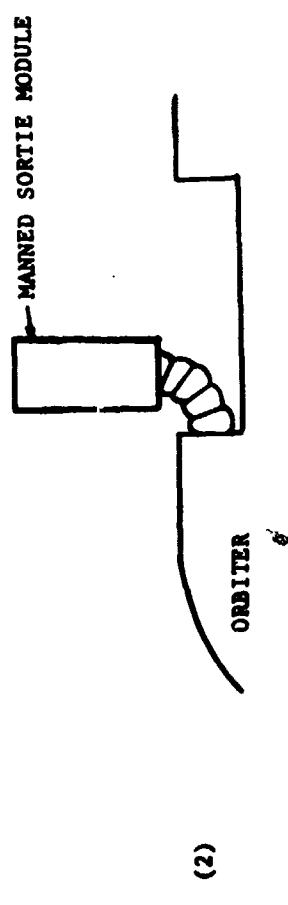


Figure 4.3-3. Primary Manned Sortie Module Deployment Options



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#### 4.3.2 Sortie Module Compartmentation Analysis

The candidate sortie module configurations of Section 4.3.1 were evaluated for their capability to cope with selected credible emergencies of Table 4.1-1. The selected credible emergencies are those which apply to the sortie modules and can lead to compartmentation oriented requirements. They are:

- . Fire/toxic environment
- . Explosion
- . Emergency evacuation
- . Loss of pressure
- . Failure to open internal hatch between pressure isolateable volumes
- . Failure to close external airlock hatch when returning from EVA
- . Failure to open internal airlock hatch when returning from EVA

The analysis methodology is similar to that employed for the orbiter in Section 4.2 and involves establishing major assumptions, developing operational options for coping with the credible emergencies, and evaluating the options to arrive at recommended requirements.

The major assumptions are identical to that employed for the orbiter except for the following variances:

- . Airlock compartment for EVA can be V1, V2, or airlock on sortie module
- . Achieving safety via EVA from the sortie modules to the orbiter is considered a possible option. This is in contrast to the orbiter assumptions where for developing orbiter operational options, it was assumed that safety would not be achieved by performing EVA to transfer from one orbiter compartment to another.

##### 4.3.2.1 Operational Options

The operational options available to cope with the above selected credible emergencies are shown for each of the candidate sortie module configurations, in Figures 4.3-5A through 4.3-5G. Again, as for the orbiter analysis, an option which is universally available for all emergencies is to "take the risk". A program decision not to accept the safety recommendations implies that the risk associated with the emergency is being taken. A second option which is universally available for all sortie module emergencies is to use the orbiter for refuge.



Three options are available to cope with a fire/toxic environment, as can be seen from Figure 4.3-5A; to seek refuge in a pressure isolateable sortie module compartment in a fire isolateable compartment or in the orbiter. Regardless of the option selected, the requirement exists to extinguish the fire. Purging of the atmosphere and return to the affected compartment is necessary only if passengers are required to abort in the affected compartment or if it is required to effect corrective action which if not made could affect personnel/vehicle safety during an abort.

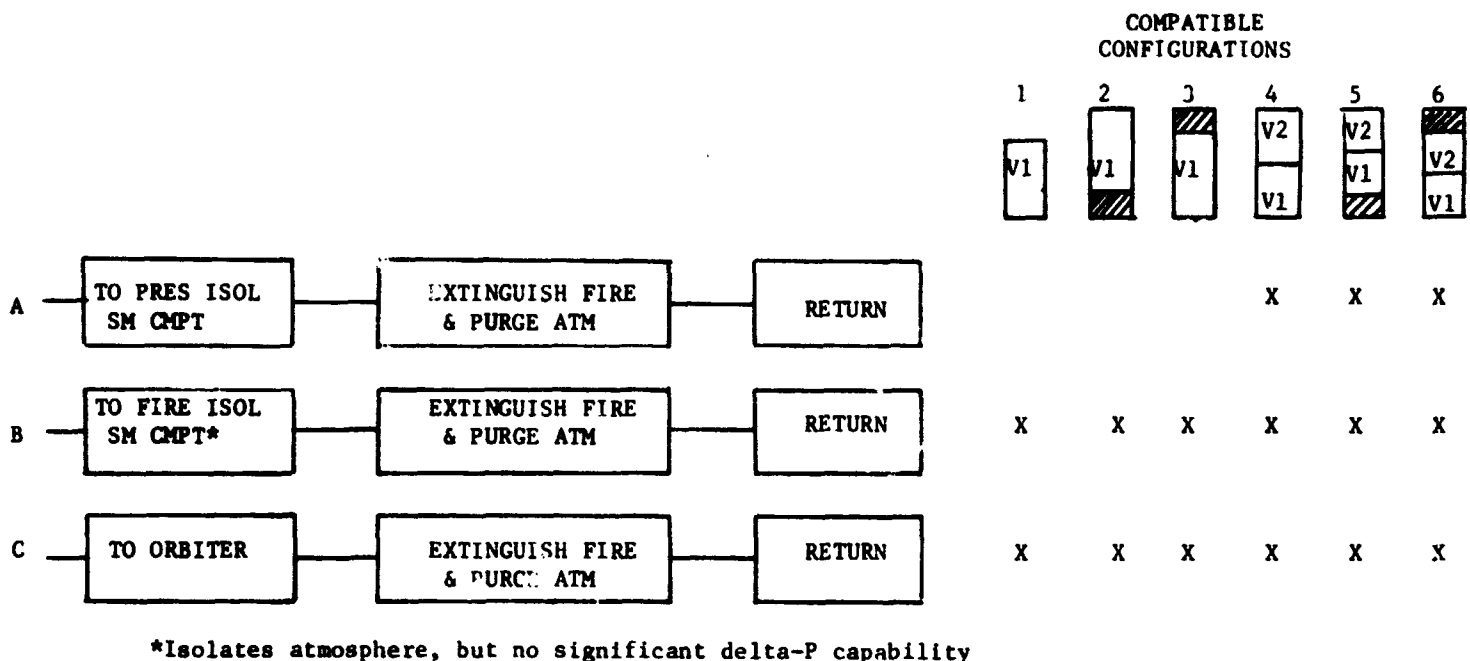


Figure 4.3-5A. Options - Fire/Toxic Environment

A primary concern, common to all options, is that of isolating the orbiter from the smoke, fumes, heat, or otherwise toxic environment generated within the affected compartment of the sortie module. These effluents can be introduced into the habitable volumes of the orbiter via open hatches to support the escape of personnel, or via orbiter/sortie module atmosphere exchange loops.

The only option available (reference Figure 4.3-5B) to cope with an explosion for single compartment configurations is to rescue the injured personnel and evacuate all to the orbiter. In the dual compartment configurations, the additional option of seeking refuge in the second compartment is available.

An emergency evacuation, in which at least minutes of reaction time is available, requires that the affected compartment be evacuated. Again, the only option available as shown in Figure 4.3-5C, for the single compartment configurations is for personnel to egress to the orbiter. Although egress to V2 is an option if V1 must be evacuated on the dual compartment configurations, this option cannot be considered seriously because of the possibility of stranding personnel in V2 if the emergency anticipated in V1 does in fact occur.

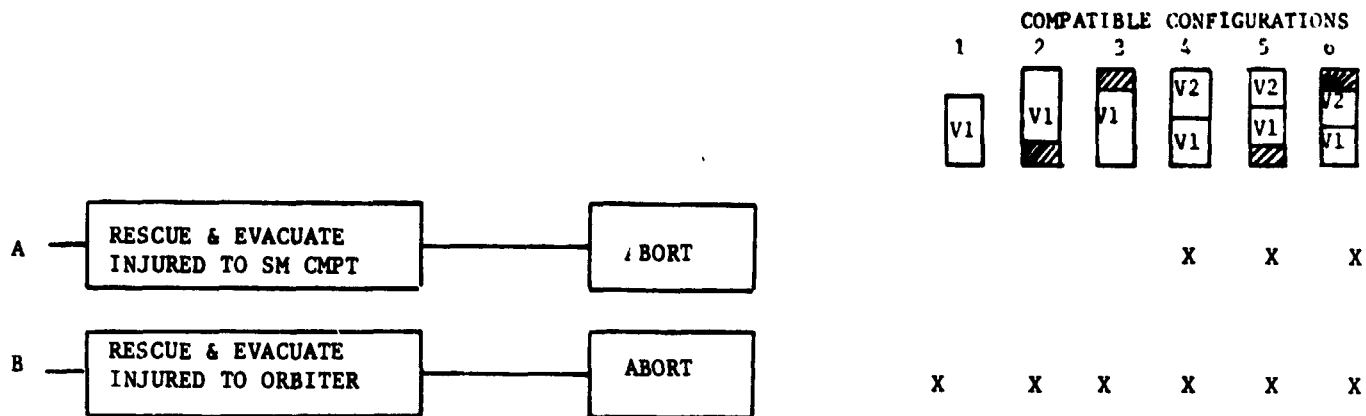


Figure 4.3-5B. Options-Explosion

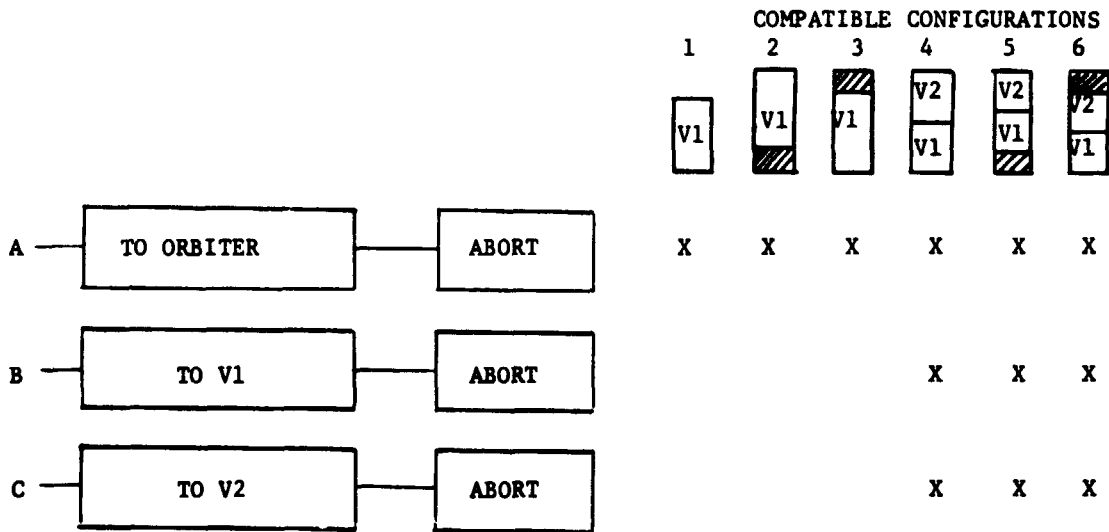


Figure 4.3-5C. Options - Emergency Evacuation

Loss of pressure can occur in either V1 or V2. The operational options available to cope with this situation are shown in Figure 4.3-3D, and include aborting the passengers in the sortie module in suits within the affected compartment, seeking refuge in a second compartment and then either performing EVA to the orbiter or performing a shirtsleeve abort within the compartment or performing shirtsleeve egress to the orbiter.

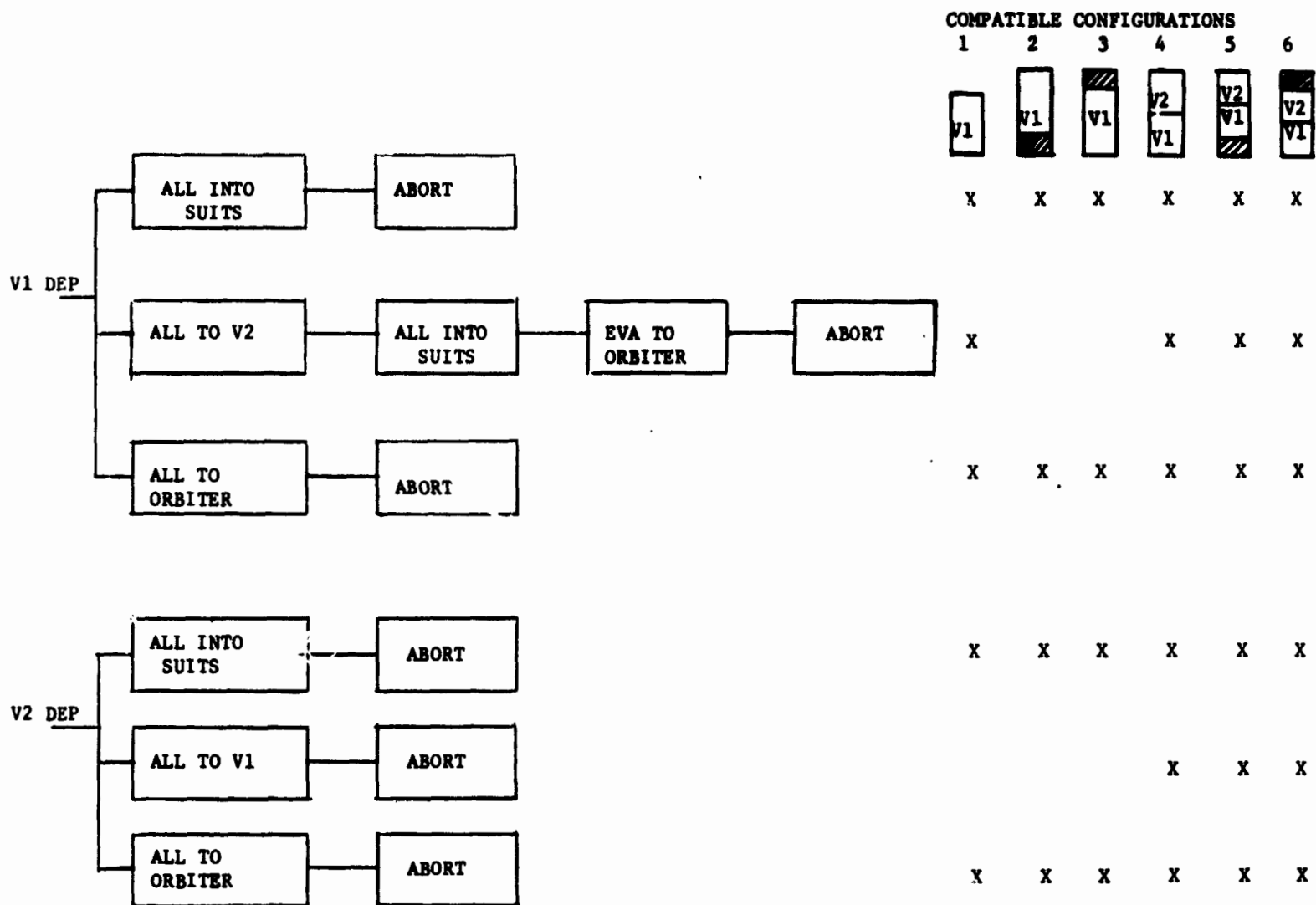


Figure 4.3-5D. Loss of Pressure

Failure to open an internal hatch during normal shirtsleeve operations results in isolation of personnel in the sortie module, and can lead to a shirtsleeve abort in the sortie module, suits for all with EVA to the orbiter, and redundant hatches or hatch opening mechanisms as shown in Figure 4.3-5E. It is noted that this situation can only occur if the hatches between sortie module volumes and between the sortie module and the orbiter are closed at some time during the mission.

The options available to cope with inability to close an internal EVA hatch upon return from EVA are many and complex as can be seen from Figure 4.3-5F. It is assumed that EVA can be performed not only from the airlock but also from V1 and V2 when an airlock is not available. If an airlock is available, then EVA is assumed to be performed from the airlock. Options available to all configurations are to abort with the EVA crewmen in the EVA compartment or to close a redundant (in series) hatch. Aside from these common options, the primary factors involved in the other options include provisions for a backup EVA ingress route on the orbiter, IVA to the orbiter or to another sortie module volume, suits for all, and egress of non-EVA personnel to the orbiter.

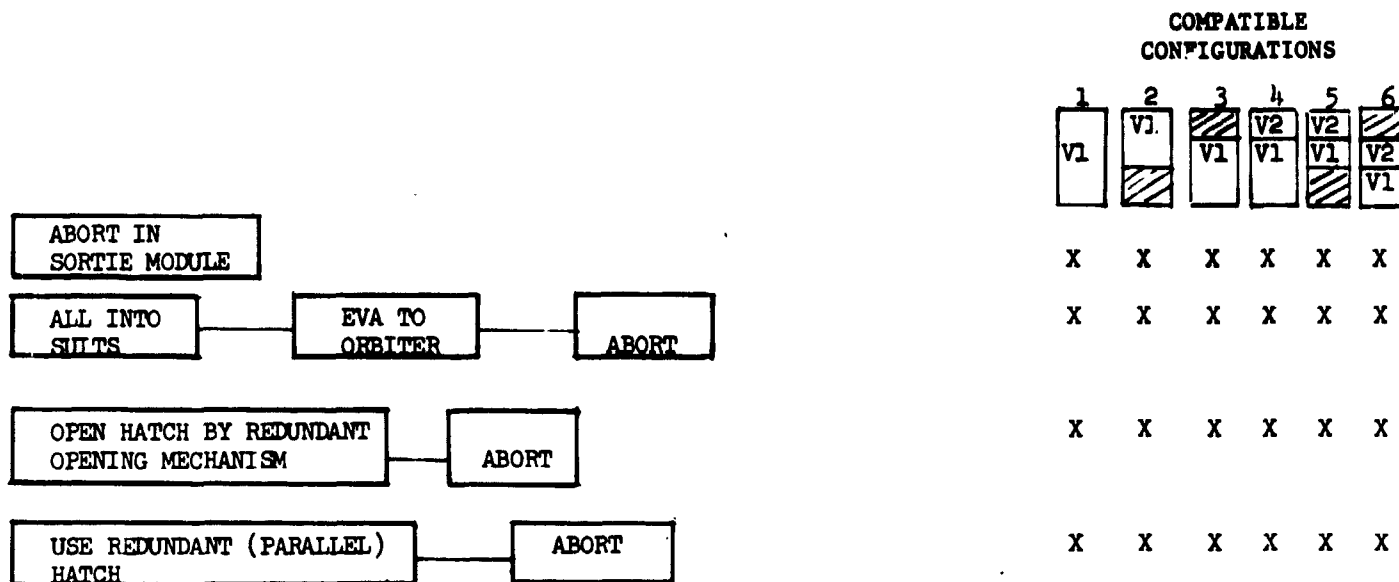


Figure 4.3-5E. Options - Fail to Open Internal Hatch  
(During Shirtsleeve Operations)

Of particular note is the sensitivity of continuing or aborting the mission to the sortie module configuration. All options which require EVA from either V1 or V2 result in abort with the single exception of closing a redundant (in series) hatch. Loss of either one of these volumes not only results in the loss of the volume to perform or support the performance of experiments, but can also result in isolating the adjacent sortie module volume and personnel in that volume from the orbiter. When EVA is performed from an airlock adjacent to the sortie module/orbiter interface as in Configurations 2 and 5, loss of the airlock results in isolation of the remaining sortie module volumes from the orbiter. However, if the airlock is located at the end of the sortie module furthest from the SM/orbiter interface, loss of the airlock does not isolate sortie module compartments from the orbiter or from one another, and therefore, enables continuation of the mission for those experiments which do not require use of the airlock.

The factors associated with the options available for coping with inability to open an internal EVA hatch when returning from EVA are nearly identical to those discussed above for inability to close external EVA hatch as can be seen from Figure 4.3-5G. A notable exception is, however, the addition of an option which employs a backup EVA ingress route on the sortie module.

#### 4.3.2.2 Major Safety Requirements Options

The operational options of the previous section are evaluated to arrive at major safety requirements applicable for each candidate sortie module configuration.

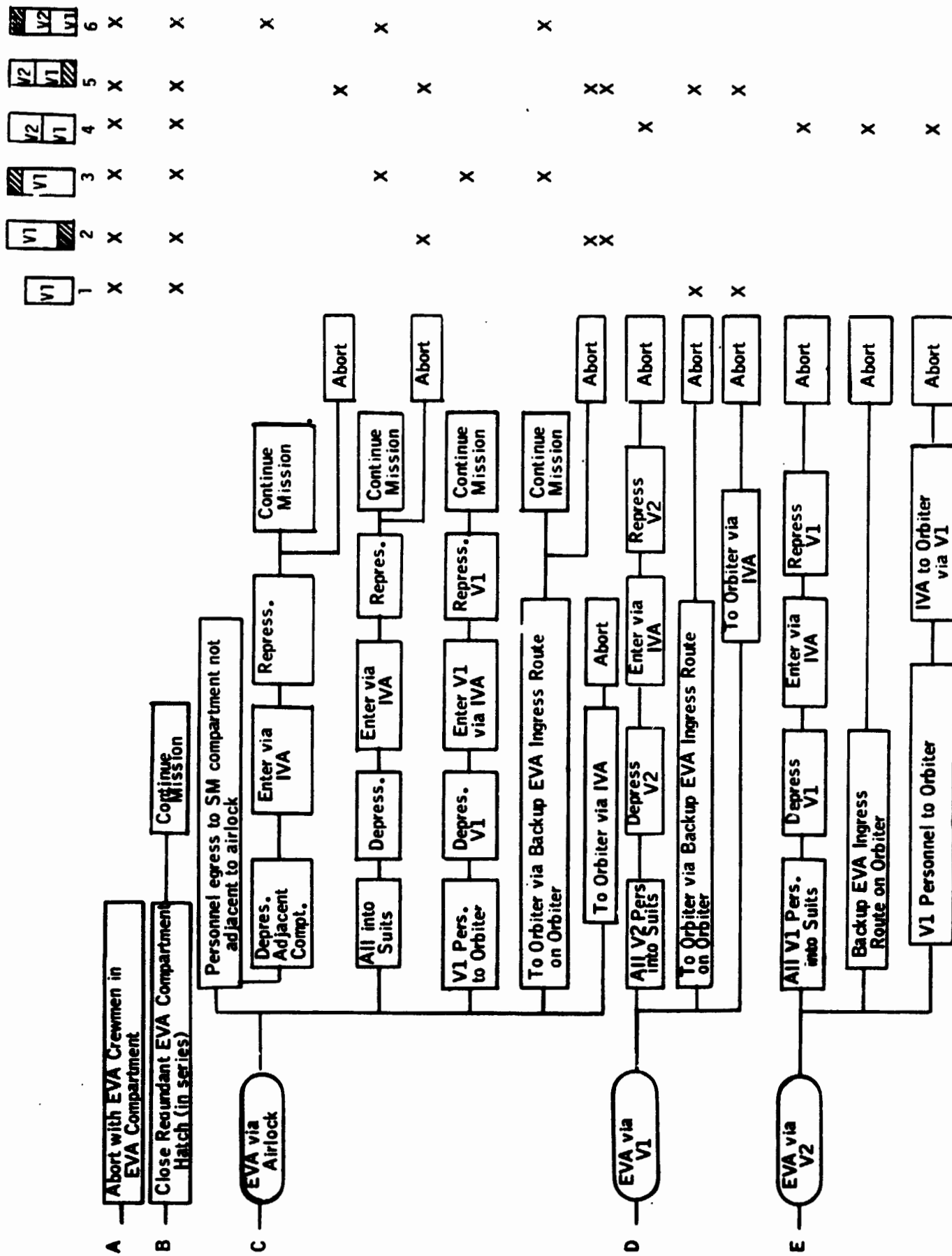


Figure 4.3-5F. Options - Inability to Close External EVA Hatch

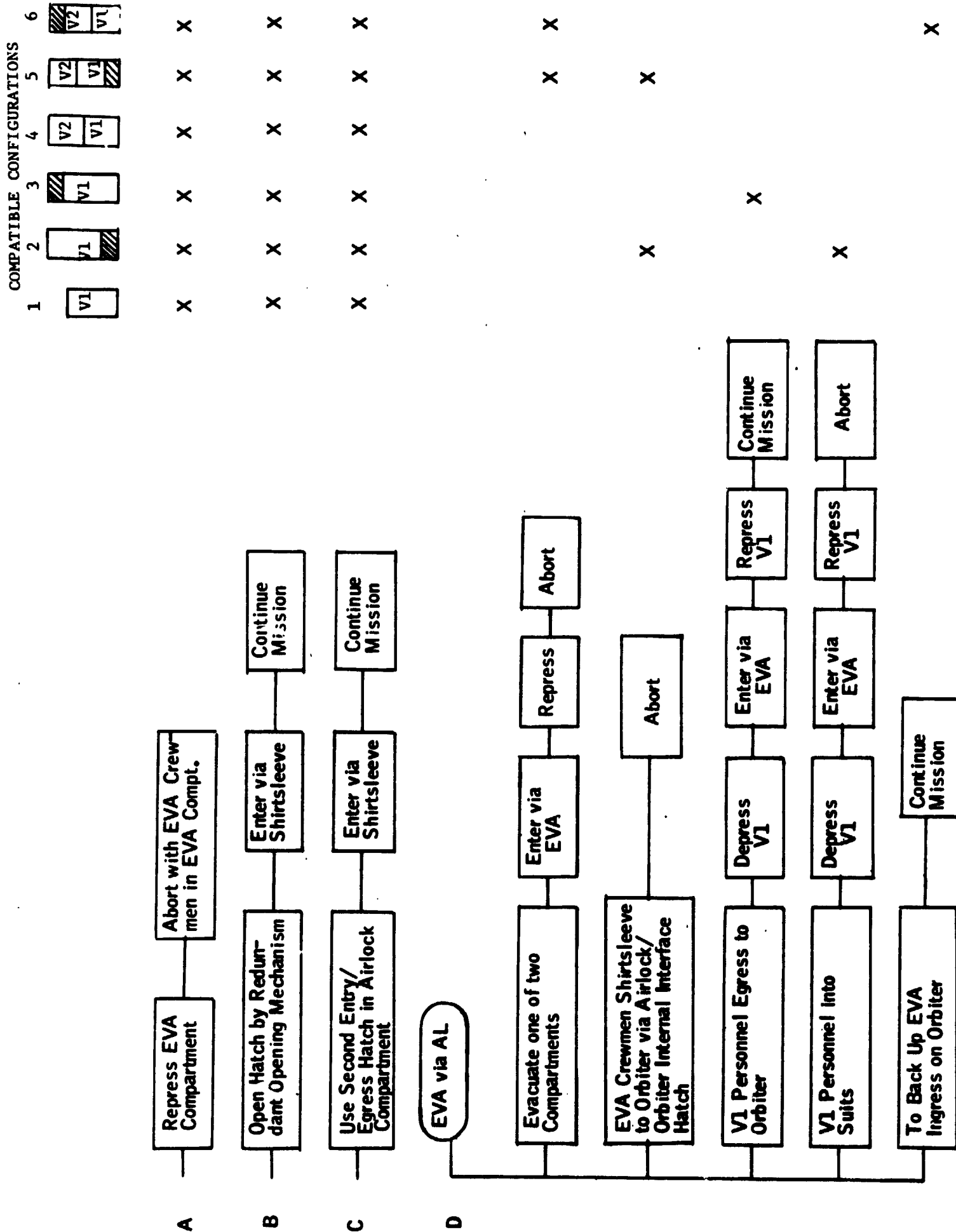


Figure 4.3-5G. Options - Inability to Open Internal EVA Hatch  
(Resulting in Inability to Return SM from EVA)

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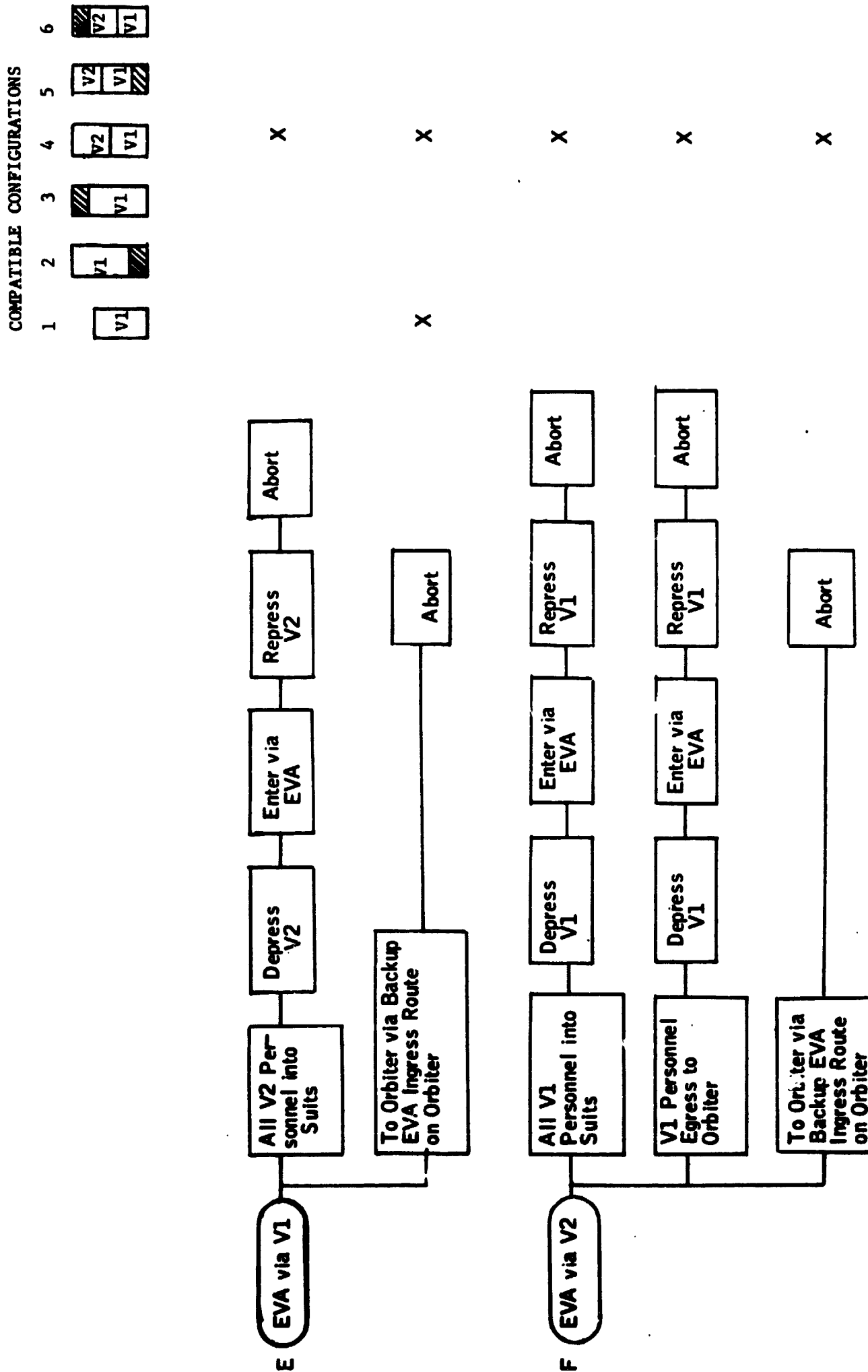


Figure 4.3-5G. Options - Inability to Open Internal EVA Hatch Resulting in Inability to Return SM from EVA) (continued)



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The requirements considered as major are those which have the potential of affecting the sortie module configuration and those which involve a compartmentation oriented interface with the orbiter. They are:

- . Fire isolation compartment
- . Suits for all
- . 8 psi suits
- . Personnel abort in a vacuum
- . Personnel shirtsleeve refuge/abort in the sortie module
- . Personnel shirtsleeve refuge/abort in the orbiter
- . EVA to/from the orbiter
- . IVA to/from the orbiter
- . Hatch requirements - These include redundant opening and closing mechanisms, redundant hatches such as parallel or back-to-back hatches, hatch locations, and whether hatches are to be normally open or normally closed.

The applicability of these requirements as they relate to each candidate sortie module configuration and credible emergency is shown in Figures 4.3-6A through 4.3-6F.

An "x" under the column of a requirement indicates that it is applicable to the emergency to which it is cross-referenced. A set of requirements, as is indicated by "x's" in the same row, are requirements which are dependent upon one another to satisfy a given operational option for a given emergency/failure. Multiple sets of requirements, any set of which is sufficient to cope with the emergency failure are identified by brackets.

Reference to Figure 4.3-6A, for example, shows that for loss of pressure of a single compartment sortie module; configuration 1, two sets of requirements are applicable. The first set requires that 8 psi suits be provided for all sortie module personnel and that the capability be provided to abort with the suited personnel in the unpressurized sortie module. The alternate requirement is for all personnel to egress to the orbiter and abort with the personnel in a shirtsleeve environment in the orbiter.

The recommended requirements, shown at the bottom of the figures, are the minimum requirements necessary to cope with all the credible emergencies.



Emergency/Failure	Fire Isol Comp	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*	
					SM	Orbit.				
Fire/Toxic Envir	X					X				or
Explosion						X				
Emergency Eval						X				
Loss of Pressure		X	X	X		X				or
Fail to Open Internal Hatch	X				X	X	X		X	
Fail to Close External EVA Hatch					X	X X	X	X	X	
Fail to Open Internal EVA Hatch					X	X X	X		X	or
Recommended						X X	X		X	

X = Requirement      \* = Redundant Opening, Closing; Location, normally open, normally closed

Figure 4.3-6A. Major Safety Requirements - Configuration 1

Emergency/Failure	Fire Isol Comp	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*	
					SM	Orbit.				
Fire/Toxic Envi.	X					X				or
Explosion						X				
Emergency Eval						X				
Loss of Pressure		X	X	X		X X				or
Fail to Open Internal Hatch		X			X	X	X		X	
Fail to Close External EVA Hatch		X	X		X	X X X	X	X		
Fail to Open Internal EVA Hatch		X			X X X	X X X	X		X	or
Recommended					X	X X	X		X	

X = Requirement      \* = Redundant Opening, Closing; Location

Figure 4.3-6B. Major Safety Requirements - Configuration 2

Emergency/Failure	Fire Isol Comp	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*	
					SM	Orbit.				
Fire/Toxic Envir	X					X				} or
Explosion						X				
Emergency Eval						X				
Loss of Pressure		X	X	X		X				} or Config.
Fail to Open Internal Hatch		X			X	X	X		X	
Fail to Close External EVA Hatch		X				X X	X		X	
Fail to Open Internal EVA Hatch		X			X	X	X		X	} or
Recommended						X X	X		X	
X = Recommended      * = Redundant Opening, Closing; Location										

Figure 4.3-6C. Major Safety Requirements - Configuration 3

Emergency/Failure	Fire Isol Compt	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*		
					SM	Orbit.					
Fire/Toxic Envir	X				X	X				} or	
Explosion					X	X					} or
Emergency Eval					X	X					
Loss of Pressure		X X	X	X	X	X X	X			} or <div>Config V1 V2</div>	
Fail to Open Internal Hatch		X			X	X	X		X		} or 4.
Fail to Close External EVA Hatch		X		X X	X X	X X	X	X	X		
Fail to Open Internal EVA Hatch		X			X X	X X	X		X	} or	
Recommended					X	X X	X		X		} or
X = Requirement      * = Redundent Opening, Closing; Location											

Figure 4.3-6D. Major Safety Requirements - Configuration 4

Emergency/Failure	Fire Isol Compt	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*	
					SM	Orbit.				
Fire/Toxic Envir	X				X	X				or
Explosion					X	X				or
Emergency Eval					X	X				or Config.
Loss of Pressure		X	X	X	X	X	X			or V1 V2
Fail to Open Internal Hatch		X			X	X	X		X	or 5.
Fail to Close External EVA Hatch		X		X	X X X X	X X X X	X	X	X	or
Fail to Open Internal EVA Hatch					X X X	X X X	X	X	X	or
Recommended					X	X X		X	X	or
X = Requirement * = Redundant Opening, Closing; Location										

Figure 4.3-6E. Major Safety Requirements - Configuration 5

Emergency/Failure	Fire Isol Compt	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter	IVA To/From Orbiter	Hatch Rqmts*	
					SM	Orbit.				
Fire/Toxic Envir	X				X	X				or
Explosion					X	X				or
Emergency Eval					X	X				or Config.
Loss of Pressure		X X	X	X	X	X X	X			or V1 V2
Fail to Open Internal Hatch		X			X	X	X		X	or 6.
Fail to Close External EVA Hatch				X	X X X	X X	X		X	or
Fail to Open Internal EVA Hatch					X	X	X		X	or
Recommended						X X	X		X	or
X = Requirement * = Redundant Opening, Closing; Location										

Figure 4.3-6F. Major Safety Requirements - Configuration 6

A summary of the recommended requirements for all six candidate sortie module configurations is shown in Figure 4.3-7. As can be seen from an inspection of the chart, only four requirements are involved in the recommendation. These are personnel shirtsleeve refuge/abort in the orbiter, personnel shirtsleeve refuge/abort in the sortie module, EVA to and from the orbiter, and hatch requirements. Of these requirements, only one, the requirement for personnel shirtsleeve rescue/abort in the sortie module is not common to all configurations. This is because it is peculiar to those configurations in which an airlock or a compartment used as an airlock is located between the sortie module and the orbiter. Emergencies involving internal or external hatches in these compartments during EVA result in isolating personnel in the sortie module and require the capability to abort with personnel in the sortie module.


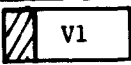
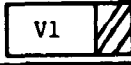
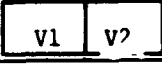
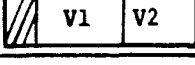
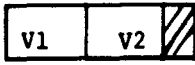
Sortie Module Configuration	Fire Isol Compt	Suits for All	8 PSI Suits	Pers Abort in Vacuum in SM	Personnel Shirtsleeve Refuge/Abort		EVA To/From Orbiter**	IVA To/From Orbiter	Hatch Reqs** ***	
					SM***	Orbit.				
1. 						X X	X		X	} or
2. 					X	X X	X		X	
3. 						X X	X		X	
4. 					X	X X	X		X	
5. 					X	X X	X		X	
6. 						X X	X		X	
Common to All						X X	X		X	} or
Required for All						X				
X = Requirement * = Redundant Opening, Closing; Location ** = Applies only if EVA is performed from Sortie Module *** = Only applies if EVA is performed or internal hatch is normally closed										

Figure 4.3-7. Summary of Recommended Requirements

Also worthy of note is that the hatch requirements which involve redundant opening, closing, and locations are applicable only if EVA is performed or internal hatches are normally closed.

The only requirement which is common to all candidate configurations and recommended sets of requirements is that of personnel shirtsleeve refuge/abort in the orbiter. The underlying rationale for recommending this all encompassing high level requirement is that regardless of the sortie module configuration, exit to and refuge in the orbiter is the natural goal for emergencies which do not cut off the normal egress path to the orbiter.

Because implementation of this requirement can significantly reduce or eliminate the imposition of other significant requirements on the sortie modules, such as fire isolation compartment, suits for all, 8 psi suits, and personnel abort in a vacuum in the sortie module, additional attention is given in the next section to ensuring availability of an egress path to the orbiter, and to controlling hazards which could cut off the egress path.

#### 4.3.3 Emergency Egress to Orbiter from Sortie Module

The analysis of 4.3.2 shows that the position of the sortie module on the orbiter, or single or dual sortie module configurations are not important factors in the safety evaluation. The most important configuration oriented safety considerations are ensuring an egress path to the orbiter, and the identification and control of hazards which could cut off the egress path(s). Three basic configuration concepts, shown in Figure 4.3-8, are available for providing emergency egress to the orbiter for an emergency, such as a fire or explosion, which has blocked the normal egress route. The first concept employs an airlock on the far end of the module. Egress to the orbiter can either be by EVA through an EVA hatch on the airlock, or shirtsleeve if a docking port were on the airlock and a manipulator were used to undock the module, rotate it 180 degrees, and redock it to the orbiter. The second concept, which is similar to that employed on the NR Modular Space Station modules, uses an internal floor to divide the module horizontally into two basic volumes. Access doors (or openings) are provided in the floor at each end of the module with sufficient clearance underneath the floor to allow shirtsleeve personnel to maneuver to the exit at the orbiter interface and egress. The third concept, dual attach, shows two modules attached to the orbiter, with a curved arrow indicating a path from one module to the other and then to the orbiter, labeled 'DUAL ATTACH'.

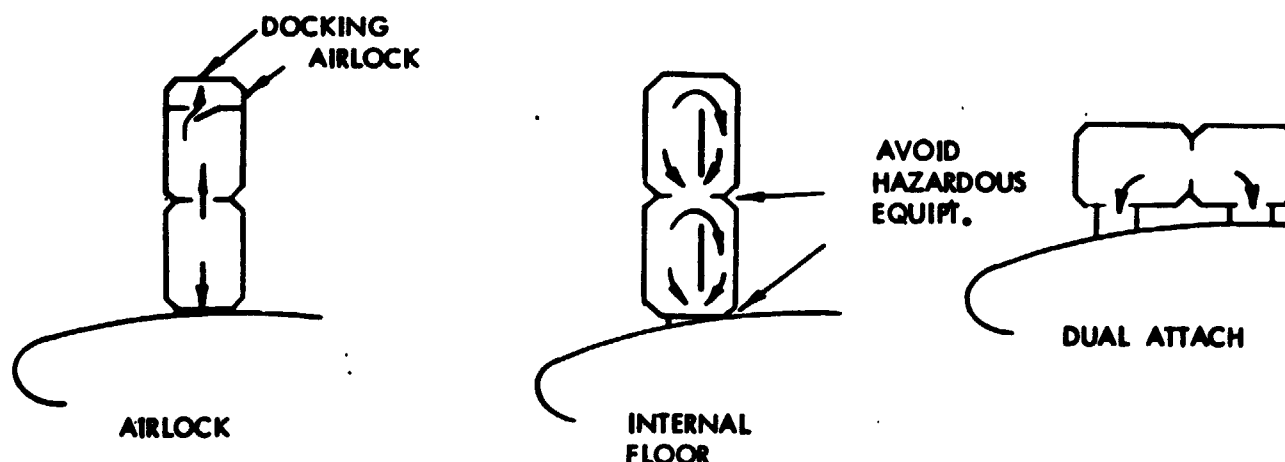


Figure 4.3-8. Emergency Egress From Sortie Module



The third concept, which requires dual docking ports on both the orbiter and sortie module (or equivalent schemes to provide a closed arrangement), is the ideal safety configuration since it provides for immediate shirtsleeve egress to the orbiter from either end of the module. However, this is not considered practical because it is not compatible with current orbiter concepts which are configured with, at most, one docking port.

A fire/toxic environment in the sortie module requires at a minimum, as in the single compartment orbiter configuration, the capability to vent the sortie module atmosphere to space to control the produced heat and pressure within acceptable limits, and to contain the smoke, fumes and other toxic by-products of combustion to the sortie module by creating a slightly lower pressure in the sortie module relative to the orbiter during egress of the experimenters to the orbiter.

An alternative approach to the pressure differential scheme is to provide an airlock capable of holding all experimenters simultaneously, between the orbiter and sortie module. To rid the airlock of the toxic effluents which have followed the experimenters during their escape, the airlock would be either purged with a nitrogen/oxygen atmosphere, in which case suits would not be required, or vented to space, which requires suits for all experimenters.

The ideal location for hazardous equipment, such as high pressure bottles and cryogenics storage vessels, is on the end of the module which is furthest from the orbiter interface. Hazardous equipment placed at the module-to-orbiter or module-to-module interface could, in the event of an accident, cut off all the egress paths to the orbiter.

An alternative to cope with any emergency which jeopardizes the safety of the orbiter, once all personnel are evacuated from the sortie module, is to release or eject the sortie module from the orbiter.

#### 4.3.4 Consideration of Catastrophic Emergencies

Consideration of a catastrophic emergency in the sortie module such as loss of pressurization within a few seconds leads to consideration of means to prevent propagation of the emergency or its effects to the orbiter and its crew. One method, proposed by General Dynamics for the RAM program is to keep a hatch between the orbiter and sortie module in a normally closed position. In particular, the General Dynamics concept calls for an orbiter airlock between the orbiter and sortie module. During orbital operations, the airlock hatch on the orbiter side is normally closed while the hatch adjacent to the sortie module is normally open. This concept is intended to provide rapid egress, via the open airlock hatch, of the sortie module personnel to the airlock in the event of a non-catastrophic emergency in the sortie module or conversely to inhibit or otherwise provide an additional margin of protection from, via the closed airlock hatch, the propagation of a catastrophic emergency to the orbiter.

The airlock also provides via purging or venting, a means to expel the contaminated atmosphere which may have followed the experimenters during their escape.



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The following points must also be considered, however, as related to the airlock and the normally closed hatch arrangements.

- The airlock must be capable of supporting all experimenters simultaneously. This is required whether or not the experimenters are in shirtsleeves as they would be if a nitrogen/oxygen atmosphere purging technique were used, or if in suits as would be the case if venting to space were employed to rid the airlock of a contaminated atmosphere. This requirement to support all personnel in the airlock is in direct conflict with all known shuttle studies conducted to date which have considered only a two-man airlock.
- The experimenters are isolated in the sortie module during use of the airlock for EVA. The situation is further aggravated if a problem occurs during EVA which inhibits repressurization of the airlock, or if an unplanned depressurization of the airlock occurs.
- The emergency "failure to open an internal hatch" is credible only for configurations in which hatches are located such that failure to open a closed hatch precludes shirtsleeve transfer from one pressure isolateable volume to another. The "normally closed" hatch concept makes this emergency credible and leads to redundant hatch mechanisms, redundant parallel hatches, suited operations or to accept the risk.
- A normally closed hatch between the orbiter and sortie module decreased the amount of time available for the experimenters to seek refuge from a rapid, but not necessarily catastrophic, depressurization of the sortie module. An example of the typical difference in reaction time available between having an orbiter/sortie module hatch open and closed can be realized by considering the effects of a two-inch hole in the sortie module. Assuming a volume of  $42 \text{ m}^3$  (1500 cu ft) for the sortie module and  $66 \text{ m}^3$  (2360 cu ft) for the orbiter, approximately one minute is available for all experimenters to egress to the airlock and close the airlock/sortie module hatch when the airlock/orbiter hatch is normally closed. If this hatch were normally left open, exposing a total orbiter plus sortie module volume of  $108 \text{ m}^3$  (3860 cu ft) to be depressurized, the available reaction time would be increased to approximately three minutes.

#### 4.3.5 Conclusions and Recommendations

Conclusions reached from the analysis are:

- A sortie module consisting of two separate pressurized modules does not have any significant safety advantages compared to a single module version. In both cases, the orbiter is available as a separate refuge compartment.



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- . No safety requirement exists for an airlock between a sortie module and an orbiter, provided it is acceptable to abort a particular mission if a depressurization or contamination problem arises in the sortie module. An airlock between orbiter and sortie module could be useful in providing IVA maintenance capability in such an event, but also poses the additional risk of isolating personnel in either vehicle if a similar problem arises in the airlock.

Recommendations made are as follows:

- . The airlock, if provided, should be configured such that isolation of the sortie module crew from the orbiter does not result during the performance of EVA from the airlock. If this is not practical, then the emergency capability to de-orbit all personnel in the sortie module or in the orbiter should be provided, or the capability should be provided to transfer personnel in the sortie module to the orbiter via EVA to enable an abort of the mission.
- . A means of emergency exit (dual egress capability) should be provided in sortie modules, for example, by a longitudinal floor providing independent personnel routes above and below the floor.
- . Emergency accommodations should be provided in the orbiter for all passengers through an abort.
- . A means should be provided to release the sortie module from the orbiter. Release is differentiated from ejection in that no identified credible emergencies require a reaction time less than a few minutes, as implied by ejection.



#### 4.4 SAFETY ANALYSIS OF MODULAR SPACE STATION CONFIGURATIONS

The NR and MDAC Modular Space Station configurations resulting from Phase B studies are evaluated in this section for the inherent means available to cope with the credible emergencies of Section 4.1. The normal operations of the space station in between resupply operations are covered in Section 4.4.2, the space station assembly in Section 4.4.3, and the resupply operations in Section 4.4.4.

The analysis assumes that each of the credible emergencies can occur in any of the modular elements and that each modular element and the orbiter, when attached to the station, is a pressure isolateable volume compartment. The credible emergencies considered lead to a number of basic criteria which are used to evaluate the station configurations.

##### 4.4.1 Candidate Space Station Configurations

The candidate space station configurations selected for this task are those resulting from the NR and MDAC Phase B Modular Space Station studies (Figure 4.4-1). Both configurations exhibit the capability to add additional core modules along the longitudinal areas to facilitate growth from the initial station 6-man capability to a 12-man growth station or a space base. Module identification numbers on the figures are indicative of the sequence in which the shuttle delivers the modules during the station assembly phase.

Integrated pressure volume summaries, of the NR and MDAC concepts, which identify the primary safety related items of test/isolation, scientific, IVA, EVA, contingency, and pressure isolatable volumes in addition to hatch locations, are shown in Figure 4.4-2.

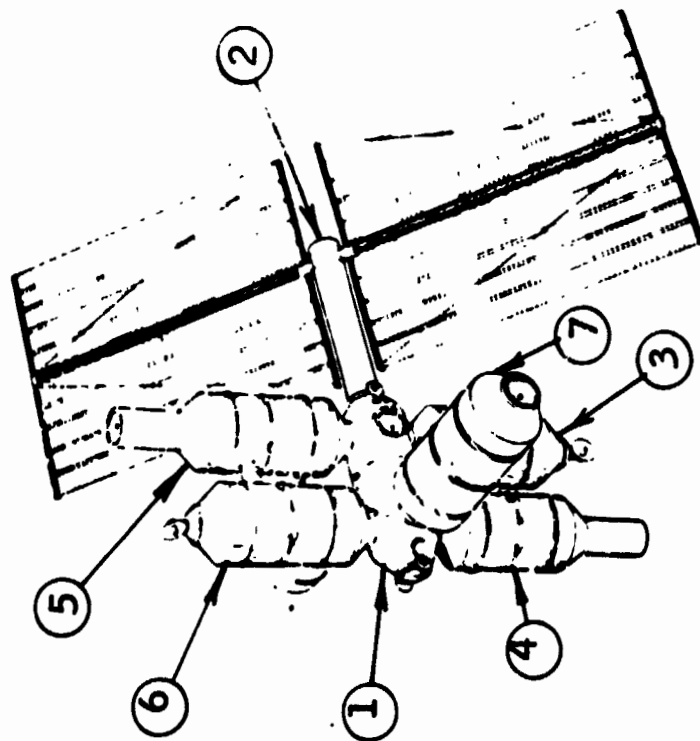
The MDAC station forms an open configuration while the NR station, through application of the auxiliary passages to interconnect modules, falls into the closed configuration class. The basic difference between the open and closed configurations is that an obstruction isolates a volume of that element from other parts of the station. In a closed configuration, however, a single cut through an element (with the exception of the attached solar array power source and side mounted module on the NR station) cannot isolate volumes of the station.

The MDAC station relies on airlocks on the ends of the radially and end mounted modules to provide a refuge haven for the crew in the event of an emergency in these volumes. The NR station, however, is divided into two basic volumes, each of which is provided with life support and station control authority from a pair of diametrically opposed modules encompassing these functions. Each volume is capable of operating independently of the other volume and of sustaining a crew of six at emergency levels for 48 hours.

Three shirtsleeve access routes are available on the NR station between the two basic volumes as provided by the airlock and the two auxiliary passages. IVA between volumes is possible only through the core module airlock. EVA, however can be performed not only from the airlock, but also from airlocks attached to the ends of the life support modules.



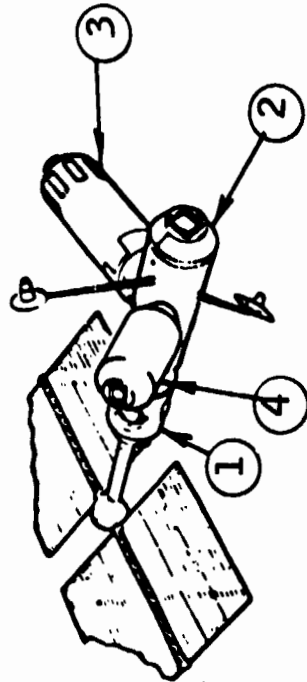
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MODULE

1. CORE
2. POWER
3. CONTROL/CREW
4. LIFE SUPPORT/LABORATORY
5. LIFE SUPPORT/LABORATORY
6. CONTROL/CREW
7. CREW/CARGO

NR



MODULE

1. POWER/SUBSYSTEMS
2. CREW/OPERATIONS
3. GENERAL PURPOSE LABORATORY
4. LOGISTICS

MDAC

Figure 4.4-1. Candidate Space Station Configurations

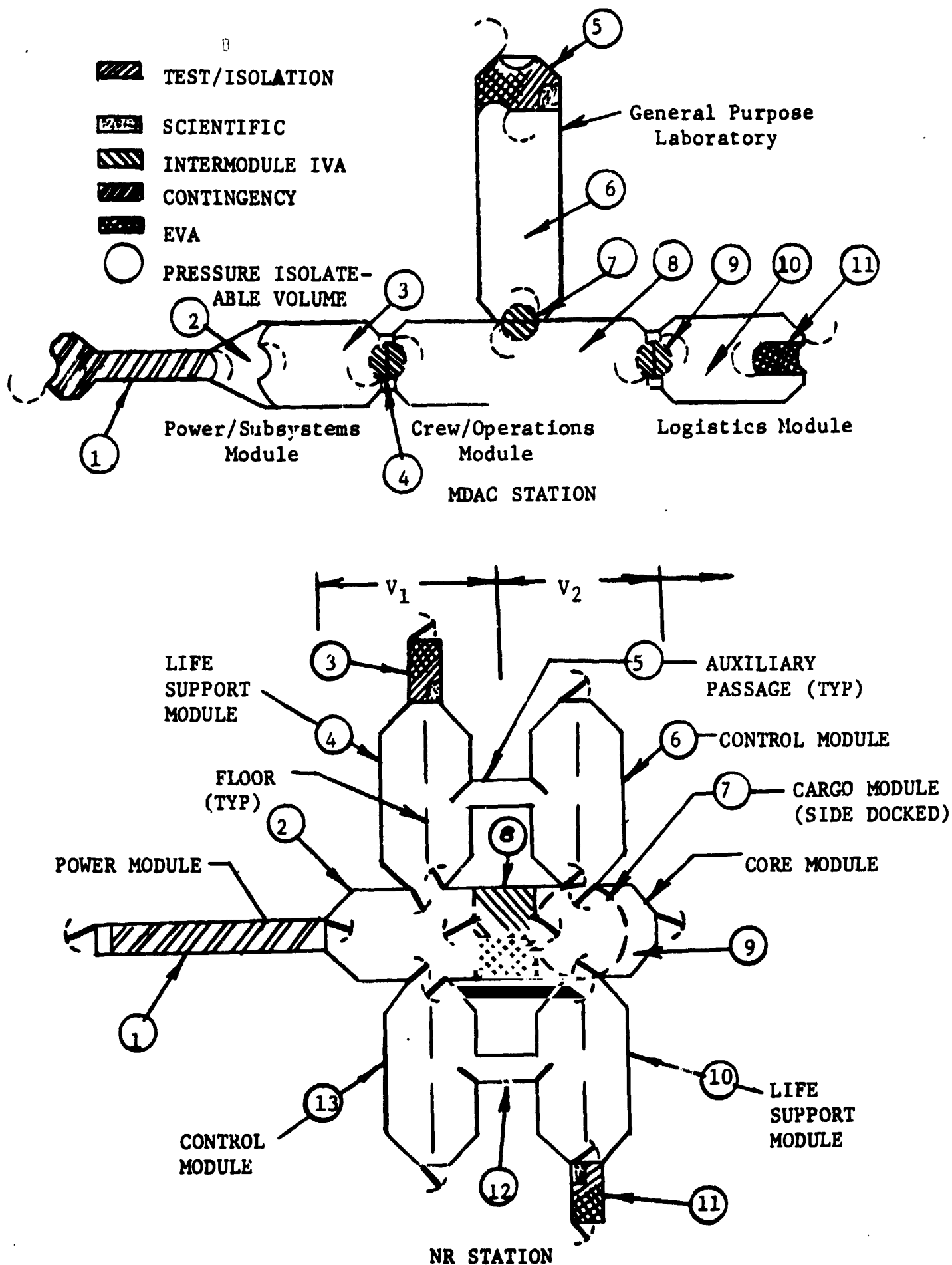


Figure 4.4-2. Integrated Modular Space Station Pressure Volume Summary



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Hemispherical shaped hatches on the MDAC station form, when two modules are docked, a spherical volume capable of accommodating two suited IVA crewmen.

#### 4.4.2 Operational Space Station Compartmentation Analysis

During the normal operations of the space station (i.e., in between re-supply), the safety of the occupants must be assured by suitable compartmentation and other provisions on the station itself, without reliance on the orbiter. Examination of the credible emergencies identified in Section 4.1 shows that three basic criteria must be satisfied. These are:

- . Dual egress criteria
- . Dual ingress criteria
- . Loss of a module/compartment criteria.

The rationale for these three criteria and their compliance in the reference configurations are discussed below. Also discussed are some additional operational safety considerations related to configuration.

##### 4.4.2.1 Dual Egress

Certain emergencies in a module, such as a fire or explosion, may cut off the normal escape route to a survivable area resulting in entrapment of the crew within the affected module. The possibility of isolating personnel in a compartment in which an emergency has occurred can be reduced if multiple egress paths to a survivable area are provided within a habitable compartment. The desirability of these provisions, from the safety point of view, lead to the dual egress criteria which is stated as:

- . Normally habitable compartments of more than  $25 \text{ m}^3$  (880  $\text{ft}^3$ ) in volume shall have two or more exits into areas which provide for personnel survival.

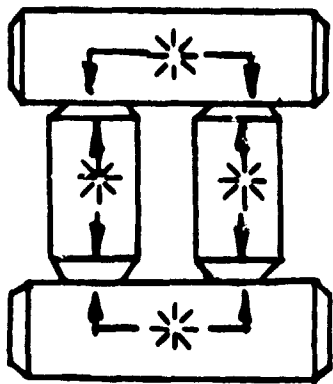
The volume below which the dual egress criterion does not apply,  $25 \text{ m}^3$  (880  $\text{ft}^3$ ), is determined by judgement and is intended to represent the minimum compartment volume below which the immediately dangerous space (heat, flames, debris) in a credible emergency would prevent crew escape and survival, regardless of the number of egress routes.

Four conceptual means of satisfying the dual egress criterion for the Modular Space Station are available:

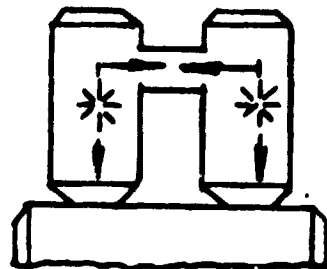
- A. Dual shirtsleeve entry/egress inherent in the configuration through the interconnection of modular elements in a "closed" ring configuration.
- B. External connecting passages, called auxiliary passages, required between proximate modules to provide the second shirtsleeve egress path.

- C. Module floors which provide escape routes above and below the floor.
- D. Airlocks with docking capability for rescue by the orbiter, or with sufficient suits for EVA escape/rescue, are required.

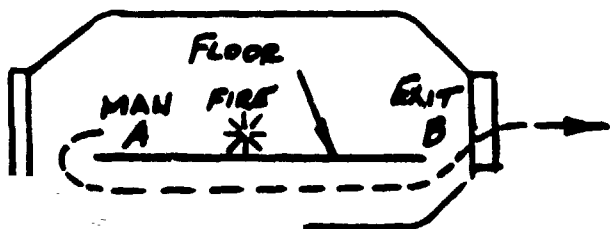
These concepts are shown schematically in Figure 4.4-3.



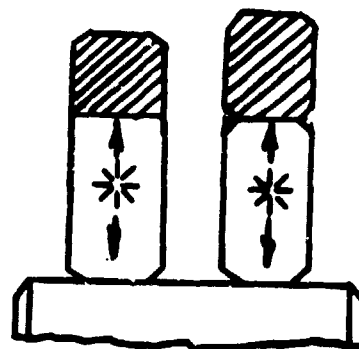
A. CLOSED RING CONFIGURATION



B. AUXILIARY PASSAGE



C. FLOOR IN MODULE



D. AIRLOCKS ON MODULES

Figure 4.4-3. Alternate Solutions for Satisfying Dual Egress Criterion



Both the NR and MDAC stations can meet the dual egress criterion by one or more of the above means as can be seen from Figure 4.4-4. Dual egress from the NR core and MDAC crew/operations modules is inherent in the configurations. Auxiliary passages are employed between the support and control modules which are docked to the core on the NR station to effect a shirtsleeve egress path between the modules. The internal arrangement of the NR standard modules also employ as an additional egress safety feature, an internal floor which has covered openings not only at the ends, but also at the auxiliary passage inlet. While the power module of the NR station and all other modules of the MDAC station have only one shirtsleeve egress path into the core or crew/operations module, a second egress path via EVA is possible. EVA may not be required from an airlock at the end of a module if a rescue shuttle is available and can be docked to the module. However, if a rescue orbiter is not available and EVA is required to gain access to the shirtsleeve volume of the station, EVA suits must be provided in all modules for all personnel inhabiting that module. On either station, normal EVA ingress to a habitable station environment would be through another station airlock. Unassisted entry to the airlock by the EVA crewmen outside the vehicle could be avoided if other station personnel entered the airlock, donned suits, and performed the necessary airlock functions.

#### 4.4.2.2 Dual Ingress

Emergencies may occur which may result not only in incapacitating personnel but also in cutting off the rescue path or opening. Because personnel may be injured or incapacitated, the time involved to effect rescue may be a critical factor for crew survival, and participation of the injured personnel in the rescue operations cannot be assumed. Consideration of these possible effects of credible emergencies leads to the dual ingress criterion:

- . Access to two or more shirtsleeve entrances into normally habitable compartments of more than  $25 \text{ m}^3$  (880  $\text{ft}^3$ ) in volume shall be immediately available from each of the other normally inhabited compartments.

Rationale for the volume constraint on applicability of the criterion is identical to that previously discussed for dual egress.

The primary difference between the dual egress and dual ingress criteria is that dual egress can be satisfied by IVA or EVA, while dual ingress can only be satisfied, because of time criticality, by shirtsleeve operations.

The ingress paths available for both subject stations are shown in Figure 4.4-5. As shown, an incapacitated crewman in a life support or control module docked to the core on the NR station can be reached in a shirtsleeve environment either by the docking port or auxiliary passage openings. On the MDAC station, an incapacitated crewman in either end of the crew/operations module, or in a module docked to the crew/operations module can be reached via only one shirtsleeve path and as such does not satisfy the dual ingress criterion. The alternate EVA route is particularly disadvantageous in this situation in that up to a 3-hour prebreathing period may be required by the rescuers, unless 8 psi suits, which require no prebreathing are used, and that all airlocks and hatches must be capable of being operated, unassisted by the injured crewman, by the EVA rescuers external to the vehicle.

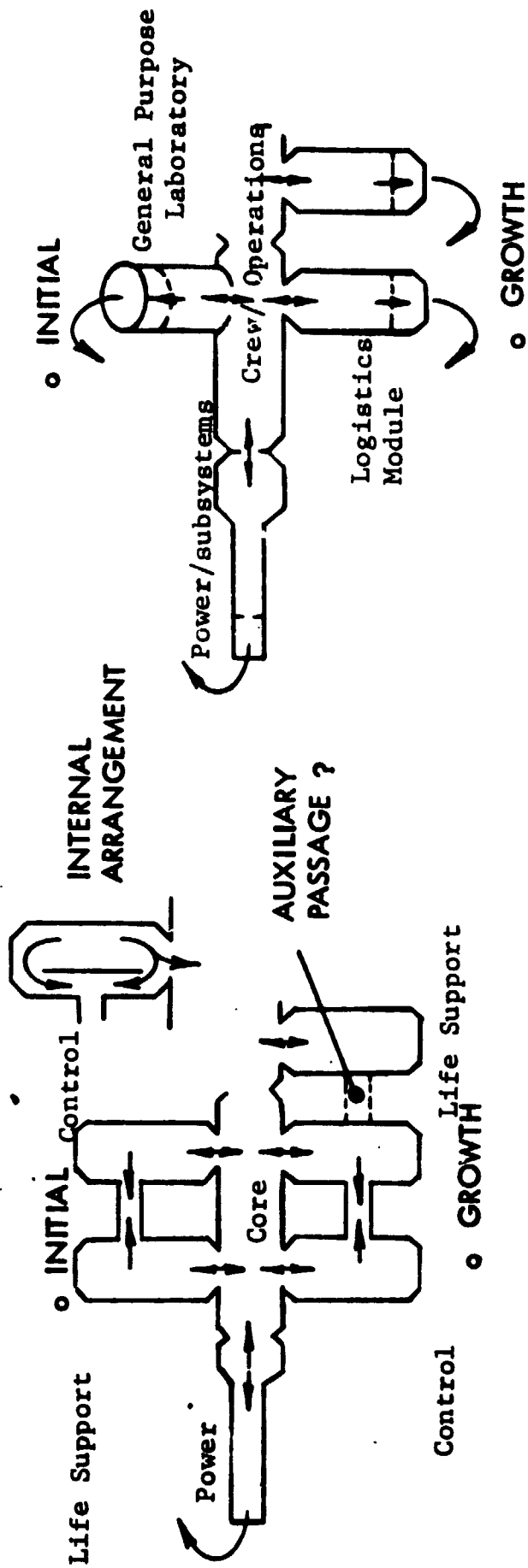


Figure 4.4-4. Dual Egress Criterion

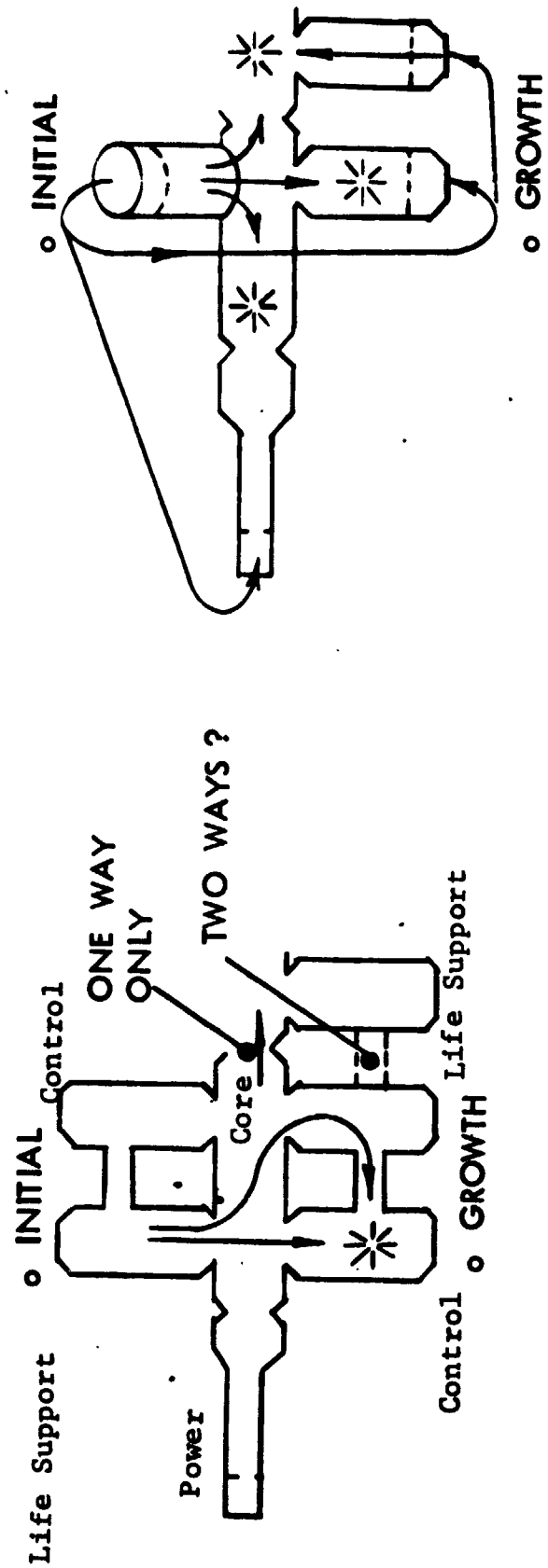


Figure 4.4-5. Dual Ingress Criterion

#### 4.4.2.3 Loss of a Module/Compartment

An emergency in a module/compartment can render life support and station control facilities in the module/compartment totally inoperable and unreparable, or in a less extreme case temporarily inoperable until repairs can be effected. During a time in which a module/compartment has lost this functional capability, life support and vehicle control provisions must be available to support personnel in another volume of the station. This support may be required until orbiter resupply/rescue is available or until repairs can be made.

This situation leads to consideration of the loss of a module/compartment safety criterion which provides for crew survival and vehicle control in a redundant survival volume until resupply/rescue/repair can be effected following loss of any pressure isolateable module/compartment. The loss of a module/compartment safety criteria is stated as follows:

- Capability shall be provided for the emergency shirtsleeve survival of all onboard personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all onboard personnel, including an available docking port.

This survival volume can be composed of a pressure isolateable compartment within a module, a whole module, or a cluster of modules. The loss of a module/compartment criterion is satisfied by the NR station as can be seen from Figure 4.4-6. The NR station is divided into two separate pressure isolateable volumes by the airlock (AL) on the core module. Each volume is serviced by two separate modules which provide crew habitability, life support, and vehicle control. Entry back into a depressurized volume from the survival volume would normally be accomplished by performing IVA through the core module airlock. However, if the station is in a configuration where airlocks have been attached to the ends of the modules containing the Environmental Control and Life Support Systems (EC/LS), EVA may be accomplished to gain entry into the depressurized volume; however, this requires that all airlock functions and controls on the affected volume be operable by the EVA crewmen external to the vehicle.

On the MDAC station, the separate volumes of the crew/operations module and the general purpose laboratory serve as survival volumes for one another. Access between these two modules, should one become depressurized, would be through a spherical IVA airlock formed by the hemispherically shaped hatches of each module at their docking interface.



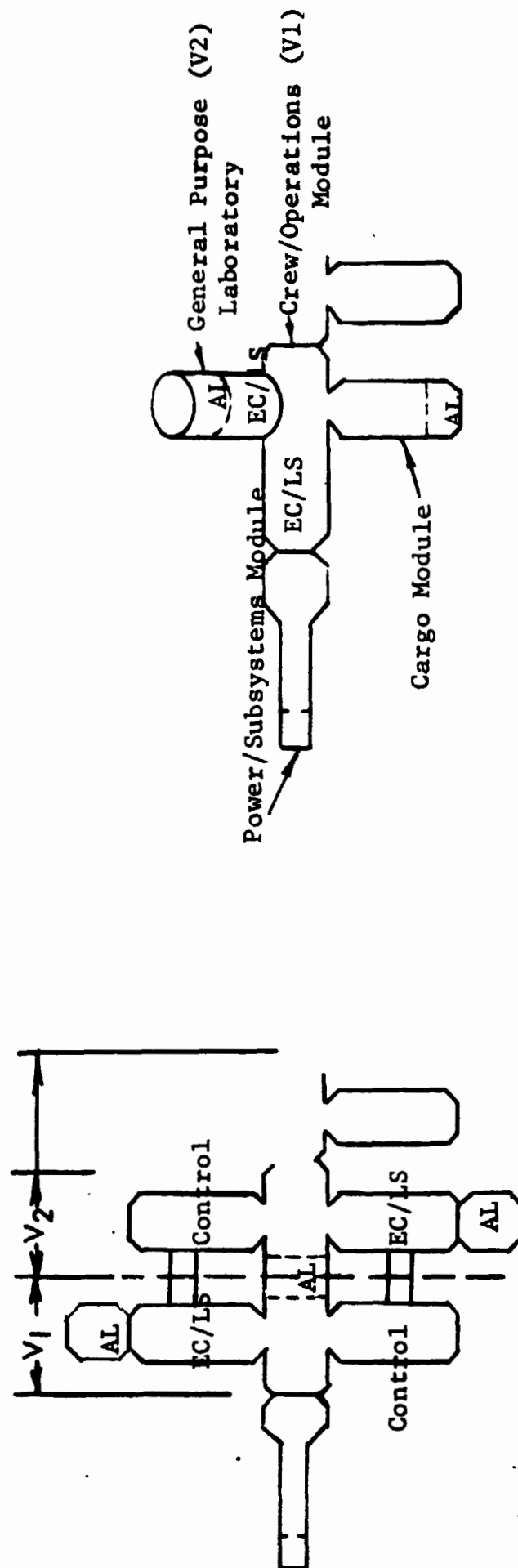


Figure 4.4-6. Loss of a Module/Compartment Criterion

The modular arrangement does not, however, satisfy via a shirtsleeve environment, the part of the loss of a module/compartiment criterion which deals with division of the station into two or more isolated volumes. As can be seen from Figure 4.4-6, a potential hazard with this modular arrangement is that loss of the crew/operations module could isolate the crew in separate modules if, for example, personnel were working in the power/subsystems module, cargo module, or a module or cluster of modules docked to the end of the crew/operations module. The only modes available to reunite the crew would be for stranded members to perform IVA through the crew/operations module using the hatch formed airlocks or to perform EVA to gain access to the general purpose laboratory through its end located internal airlock. Either return mode is disadvantageous in that it requires storage and dispersment of IVA/EVA suits and critical equipment and supplies throughout the vehicle.

#### 4.4.2.4 Other Operational Considerations

Among the safety issues emerging from the Modular Space Station studies are (1) whether interior hatches should normally be left open or closed, and (2) whether the number of crewmen in a given area at any one time should be restricted.

Although the hazards analysis performed in consonance with this task has resulted in specific requirements which relate to the above issues, a discussion of the issues as they relate to station compartmentation is given in the following sections.

##### Interior Hatch Status

In addressing such safety issues as whether interior hatches should normally be open or closed, the tradeoff decision can best be reached by comparing requirements for hatch usage imposed by potentially hazardous situations. The baseline station model assumes the primary escape route from station modules is via the berthing port hatches into the core module. In the event the primary path is blocked, a secondary route (cargo module excepted) is provided via an auxiliary port passage. Considerations such as potential difficulties in opening hatches against pressure differentials and the complexity of pressure equalization valving are the principal drivers favoring a "hatches normally open" policy. Advantages of keeping hatches closed are (1) fewer hatches to close in emergency, and (2) minimum exchange of atmosphere between volumes. Bearing in mind that auxiliary passage hatches only have to be used in emergency, and even then the normal exit is via the berthing hatch, tends to favor auxiliary passage hatches being closed. It is pointed out that some contingency situations would impose both an opening and closing action on the crew. There appears to be no strong driver for keeping hatches closed since no more than two hatches require closing in order to isolate a module, or three hatches to isolate a pressure volume. Since no credible situation to date has shown a requirement for crew evacuation in seconds rather than minutes, a "hatches normally open" policy is recommended. A decision to keep hatches open or closed is a reversible one, subject to change after operational experience.

#### Crew Size in One Area

In addressing the safety issue of the number of crewmen allowed in one area, the maximum crew congestion is most likely to occur in the dining/recreation area of either the NR or MDAC station and, as such, represents a worst case condition for crew evacuation following an emergency. Total crew assembly at one location should not in itself cause undue concern, except in areas where personnel escape routes are restricted; e.g., cargo modules, RAM's, etc. In all areas where maximum crew congestion is likely, special consideration should be given to locating potentially hazardous equipment such that crew exposure to risk is minimized. On the NR station, relocation of H<sub>2</sub> and O<sub>2</sub> accumulators from immediately below the dining/recreation area (SM-3) to a location outside the habitable environment is one example.

#### 4.4.3 Space Station Assembly

A different situation occurs during assembly of the space station. At this time the configurations of the space station are not complete, and all subsystems are not necessarily functioning. On the other hand, the shuttle orbiter is always present and attached (in the assembly operations defined in the Phase B studies) during manned operations on the space station. Because of these differences, the three basic criteria established in 4.4.2 must be re-evaluated and modified as necessary, and the implications of applying them determined.

The configurations of the space station and orbiter during the assembly operations are shown in Figure 4.4-7 for the NR station, and in Figure 4.4-8 for the MDAC station. These assembly operations are as defined in the space station Phase B final reports, but are regarded as typical only for purposes of this study. Variations, such as which docking port the orbiter is attached to, or even the order in which modules are brought up, are not expected to affect the results derived here. The assembly phase is assumed complete when the configuration of the station allows safe manned occupancy of the space station without the orbiter being present.

The terms V1, V2, V3, etc., in these figures indicate the separately pressurizable compartments available at each assembly stage. Airlocks are indicated by the letters "AL".

Also shown in these figures are the potential shirtsleeve egress paths from each module in the event of an emergency at each stage of assembly. These become the prime configuration oriented safety concern during assembly, and are discussed below under each of the three relevant criteria.

##### 4.4.3.1 Dual Egress during Assembly

The rationale for requiring dual egress during assembly is exactly the same as during normal operations, and the criteria remains unchanged; i.e., normally habitable compartments of more than 25 m<sup>3</sup> (880 cubic feet) in volume shall have two or more exits into areas which provide for personnel survival.

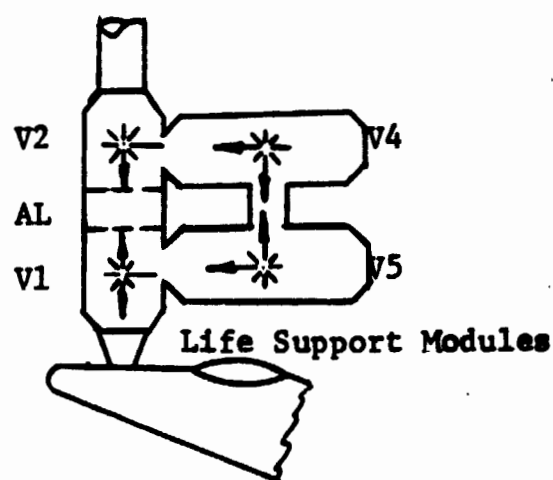
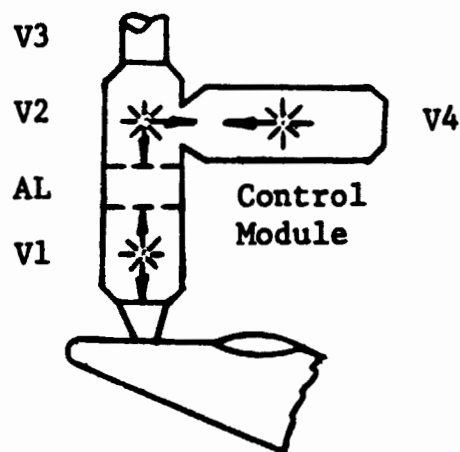
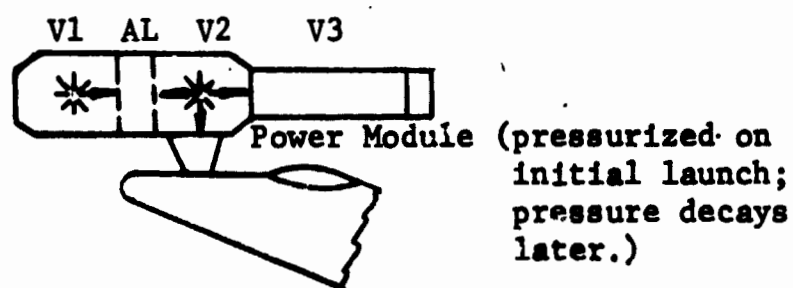
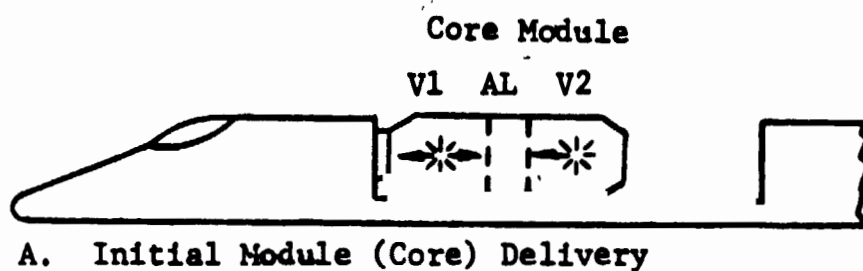
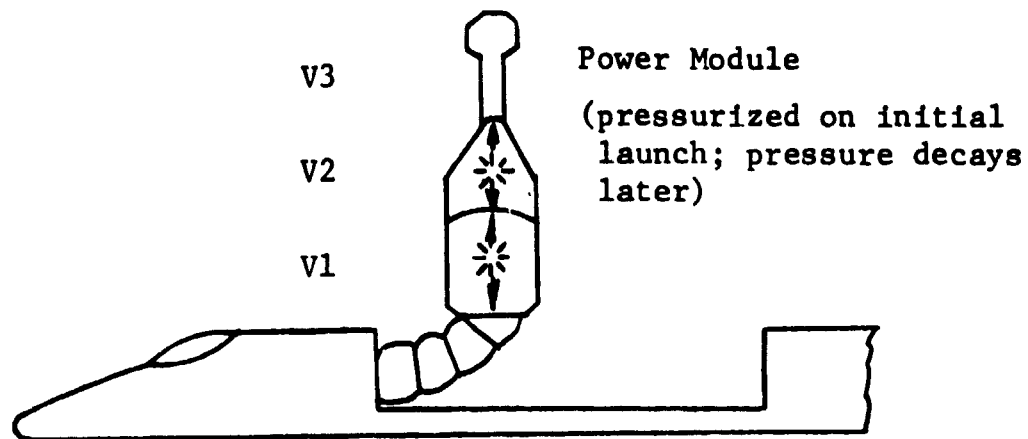


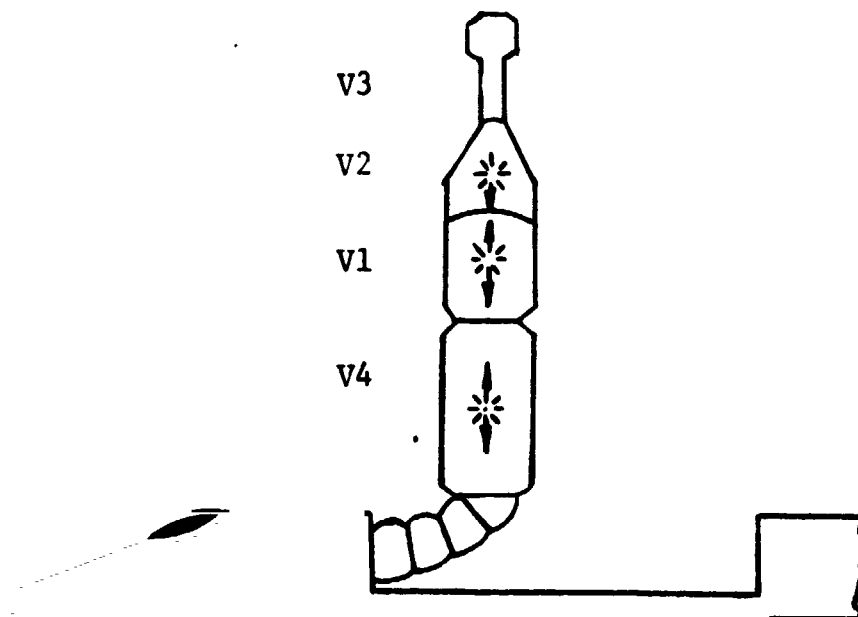
Figure 4.4-7. Egress Paths During Assembly of NR Modular Space Station



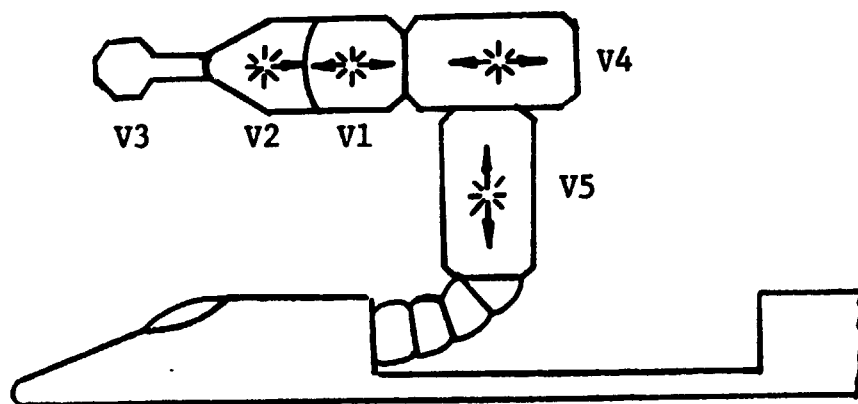
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A. Initial Module Delivery (Power/Subsystems)



B. Crew/Operations Module Delivery



C. General Purpose Laboratory Delivery

Figure 4.4-8. Egress Paths During Assembly of  
MDAC Modular Space Station



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Examination of Figures 4.4-7 and 4.4-8 shows that this criterion cannot be met in all compartments in every stage of assembly. In particular, difficulty arises with the "end" compartments of modules, since these do not lead to a habitable area. These compartments must therefore not be regarded as "normally habitable" during assembly. Three possible courses appear feasible for dealing with these compartments:

- Restrict shirtsleeve access to such compartments during buildup
- Allow access, but only after potentially hazardous equipment has been checked out, and for short time periods only
- Allow access only, in pressure suits, and have EVA escape capability in the compartment

On the NR station the criterion can be met in each module only after the configuration is "closed" by the auxiliary passages between adjacent modules, as shown in Sketch D of Figure 4.4-7.

On the MDAC station, Figure 4.4-8, the criterion can be met on the initial launch when the power module is pressurized. The power module can be used as a temporary refuge area from which the orbiter can rescue the personnel, or from which EVA can be performed. This assumes, of course, that the module is large enough to accommodate all on-board personnel. If the pressure in this module is allowed to decay, and is therefore not available for immediate refuge, the earlier remarks about restricting access to the "end" compartment apply to the MDAC station, as well.

The MDAC concept does allow two additional options, however, which would make every compartment meet the criterion. These are:

- Maintain the power module as a pressurized refuge volume during manned assembly operations
- Provide rapid pressurization capability on the power module

#### 4.4.3.2 Dual Ingress during Assembly

The rationale for dual ingress is also unchanged during assembly, and the criterion remains:

- Two or more entrances into normally habitable compartments of more than 25 m<sup>3</sup> (880 cubic feet) in volume shall be shirtsleeve accessible from each of the other normally inhabited compartments.

Visual inspection of Figures 4.4-7 and 4.4-8 shows that this criterion cannot be met during assembly on either the NR or the MDAC space station. Only when the configuration becomes "closed" in the NR station can this criterion be partially met. Since the intent of this criterion is to allow for multiple internal rescue paths to each compartment, it is particularly desirable

to have two or more immediate (i.e., shirtsleeve) access routes from the orbiter to each compartment. This is obviously a virtually impossible requirement to meet with current docking concepts.

Steps which can be taken to improve the situation include the following:

- Use the "buddy" system during assembly operations, so that each man can help the other in case of a minor accident
- For operations in known hazardous areas, potential rescue personnel may be stationed in safe adjacent areas

#### 4.4.3.3 Loss of Module/Compartment during Assembly

During manned assembly operations the orbiter is attached to the space station. It is immediately available as a refuge in case of loss of a module or compartment on the space station, and as an escape vehicle for return to earth, if needed. The intent of the criterion defined in Section 4.4.2.3 is not applicable in this situation. It is no longer necessary to provide for long-term survival, but only for rapid access to the orbiter or to a short-term survival area on the station which can be promptly reached by the orbiter.

The criterion is therefore replaced by:

- During manned space station assembly operations, loss of any one compartment/module shall still allow immediate access of all on-board personnel to the orbiter or to an independently pressure isolateable volume from which the on-board personnel can transfer to the orbiter either shirtsleeve, following orbiter redocking, or by EVA.

Inspection of Figures 4.4-7 and 4.4-8 shows that this criterion can be met in both stations at all stages of assembly. Since the loss of the module or volume is considered to allow a few minutes of reaction time (see Table 4.1-2), this means that even if the affected volume is positioned between the personnel and the orbiter, they still have time to pass through it to the orbiter. Even if the loss occurs suddenly, however, and the affected module cannot be traversed, the configurations are all such that a temporary refuge area can be provided by closing off one or more hatches, and that this area has available an accessible docking hatch to which the orbiter can transposition and dock.

No problems are therefore expected from this criterion.

#### 4.4.4 Space Station Resupply

During the resupply of the space station by an orbiter, two significant differences occur from the normal operation of the station (i.e., between resupply).



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- . If the orbiter is changing the station crew, up to twice the normal crew complement may be present, in addition to the orbiter crew.
- . The orbiter is present and is available as an additional refuge area, as well as an escape vehicle.

The first of these considerations is basically taken care of by the additional life support and volume provided by the orbiter and if needed a rescue shuttle and thus poses no additional safety issue.

Similarly, the second consideration shows an improved safety compared with the station only (which has inherent safety in itself) or with the station/orbiter combination (which provides the immediate escape or rescue capability. The resupply situation therefore has the safety advantages of both these situations, and the disadvantages of neither.

No further analysis of the resupply situation is therefore considered necessary.

#### 4.4.5 Conclusions and Recommendations

The following conclusions are made based on the analysis of section 4.4:

- . A two-pressure volume configuration, such as provided in the NR design, provides maximum operational flexibility (e.g., mission continuation) in the event of an accident in any one module. Adequate safety can, however, be provided without a two-volume arrangement, but loss of any one module (temporary or permanent) interrupts the mission and may need complex orbiter rescue operations.
- . A "closed" configuration which provides at least two independent personnel routes from any one module to any other, provides safety with shirtsleeve operations only. The NR space station design provides such a "closed" configuration by providing auxiliary passages between modules in addition to the main passageway through the core module.
- . "Open" configurations, such as the MDAC design, rely on airlocks and IVA, EVA or orbiter rescue to ensure personnel safety in situations requiring emergency evacuation of a module.
- . Special precautions must be taken during space station assembly to assure safety of personnel. These precautions include restricting access to station compartments which do not have dual shirtsleeve egress, unless the time spent in the compartment is short, potentially hazardous equipment has been checked prior to entry, EVA suits are provided, and buddy system employed.
- . Space station resupply does not present any unusual safety problems which require unique criteria, requirements or solutions.



The following recommendations are made based on the analysis of section 4.4:

- . Interconnect all modules through an auxiliary passage to provide dual shirtsleeve egress, or where this is impractical, provide a floor in the module which provides for independent personnel routes above and below the floor.
- . Design all hatches to be operable from either side to enable escape from within or rescue from outside a module/compartment.
- . Interior hatches shall normally be open, with the exception of emergency egress hatches which shall normally be closed.
- . Potentially hazardous equipment should not be located in or near areas where maximum crew congestion is likely to occur; e.g., dining/recreation areas.
- . Potentially hazardous equipment should not be located in the vicinity of the module docking interface.

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## APPENDIX A

### SUPPORTING ANALYSES-HAZARDOUS PAYLOADS

#### A.1 TYPICAL ORBITER ABORT DATA

Orbiter aborts considered in this task of the study encompassed three of five mission phases, and were investigated primarily to provide an estimate of the reaction time available to perform emergency payload functions in the event of an abort.

Prelaunch and mated ascent phase aborts were not considered. Data relative to an abort during the orbiter solo ascent, on-orbit entry, and atmospheric flight/landing phases are provided below:

1. An orbiter failure precluding successful orbit injection into a 93 by 185 km (50 by 100 nm) orbit could result in reentry into the sensible atmosphere after a relatively short (about 100 seconds) ballistic trajectory.
2. Three abort mode options are available to the orbiter during the orbiter solo ascent phase. These are shown below, together with estimated reaction times to perform both orbiter and payload contingency functions:
  - a. Continue to orbit - 50 min 7 days
  - b. Once around - approximately 50 min
  - c. Downrange landing - less than 100 sec
3. Shuttle cargo bay doors can open in approximately 1 minute.
4. Maximum Shuttle payload weight during an abort as limited by Shuttle entry and landing loads characteristics may require offloading of payload fluids, or result in increased risk with a reduction in the normal safety factor for an abort situation.

#### A.2 TYPICAL ORBITER CARGO BAY PRESSURE ENVIRONMENT

The projected cargo internal pressure time histories during ascent and reentry are shown in Figures A-1 and A-2. The figures assume that adequate venting is provided to limit the pressure differential across the orbiter cargo bay to within a structural limitation value of  $13.7 \times 10^3 \text{ N/m}^2$  (2 psi).

Table A-1. Typical Temperature Limits for the Internal Walls of the Cargo Bay

Payload External Surface Temperature °F	Cargo Bay Doors (°F)									
	Prelaunch*		Launch		On-Orbit (Doors Closed)		On-Orbit (Doors Open)		Entry	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
100	80	120	80	150	-100	150	N/A**	N/A**	-100	250
70	50	120	50	150	-100	150	N/A	N/A	-100	250
0	-20	120	-20	150	-100	150	N/A	N/A	-100	250
-300	-100	120	-100	150	-150	150	N/A	N/A	-150	250
-420	-100	120	-100	150	-150	150	N/A	N/A	-150	250

Payload External Surface Temperature (°F)	Other Cargo Bay Areas (Sides, Bottom, Ends) (°F)									
	Prelaunch*		Launch		On-Orbit (Doors Closed)		On-Orbit (Doors Open)		Entry	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
100	80	120	80	130	0	130	0	130	0	200
70	50	120	50	130	-25	130	-25	130	-25	180
0	-20	120	-20	130	-75	130	-75	130	-75	160
-300	-290	120	-290	130	-300	130	-300	130	-300	150
-420	-290	120	-290	130	-420	130	-420	130	-420	150

\*Cargo bay is purged with dry GN<sub>2</sub> for ground thermal conditioning. For bare LH<sub>2</sub> tanks, special provisions (e.g., He purging) will be required to prevent liquid air formation.

\*\*The exposed surfaces of the payload will be subjected to the deep space environment which includes a black body radiation sink at 4°K and direct sun radiation.

As is shown, the cargo bay is nearly totally evacuated in less than three minutes after launch, which is approximately four minutes before orbit injection. Therefore, for a normal Shuttle mission, the cargo bay will be vented prior to attainment of orbit.

During re-entry, approximately 40 minutes elapse after the de-orbit burn before entry into the sensible atmosphere, after which normal atmospheric pressure is reached in approximately 20 minutes.

### A.3 TYPICAL SHUTTLE CARGO BAY THERMAL ENVIRONMENT

Projected temperature limits for the internal walls of the cargo bay, as a function of payload external surface temperature, are shown in Table A-1 for payload temperatures ranging from  $-420^{\circ}\text{F}$  to  $+100^{\circ}\text{F}$  in. The table assumes that the Shuttle utilizes  $\text{LO}_2$  and  $\text{LH}_2$  propellants with storage tanks in the proximity of the cargo bay.

As can be seen from the table, the low temperature extreme of  $-420^{\circ}\text{F}$  on the sides, bottom, and ends of the cargo bay can result during the on-orbit and entry phases, and also the cargo bay temperature is very sensitive to payload temperature. The maximum temperature of  $250^{\circ}\text{F}$ , which occurs on the inside of the cargo bay doors during entry, is insensitive to the payload external surface temperature.

### A.4 UPPER STAGE VEHICLES

Table A-2 summarizes the main characteristics of the six vehicles considered. Figures A-3 through A-8 show the salient features and configurations of these vehicles. The last figure shows one possible configuration of the OOS or tug and should be regarded as typical only.

Table A-2. Main Characteristics of Upper Stage Vehicles

Name	Manufacturer	Engines	Total Thrust KN, (Klb)	Main Engine Propellants	Diameter (ft)	Length (ft)
Agena	Lockheed	1	71(16)	UDMH & IRFNA	1.5 (5)	6.4 (21)
Centaur	GD/Convair	2	133(16)	$\text{LH}_2$ & $\text{LO}_2$	3.0 (10)	9.6 (31.5)
Transtage	Martin	2	71(16)	A-50 & $\text{N}_2\text{O}_4$	3.0 (10)	4.4 (14.5)
Burner II	Boeing	1	48(10)	Solid Propellant	1.5 (5)	1.4 (4.5)
Apollo Service Module	North American Rockwell	1	54(21)	A-50 & $\text{N}_2\text{O}_4$	4.0 (13)	6.9 (22.5)
Orbit-to- Orbit Shuttle (OOS)/Tug	---	1, 2 or 4	67-110 (15-25)	$\text{LH}_2$ & $\text{LO}_2$	4.6 (15)	11.0 (36)

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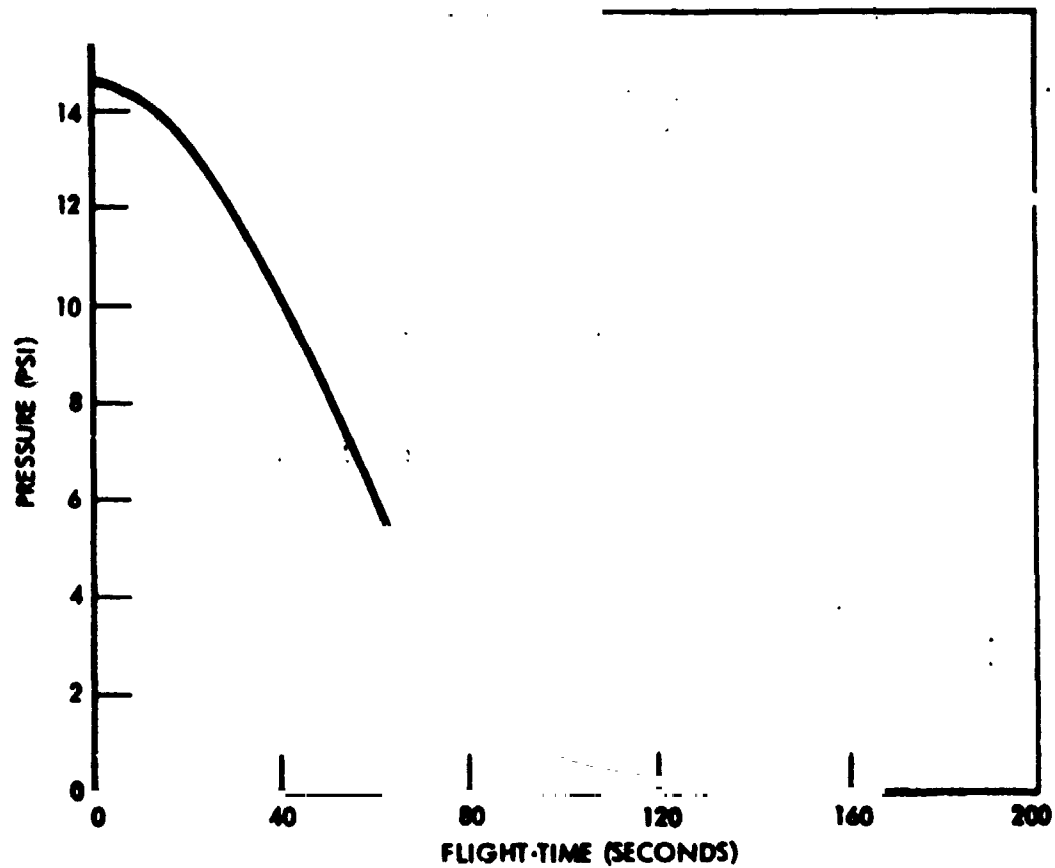


Figure A-1. Cargo Bay Internal Pressure Time History During Ascent

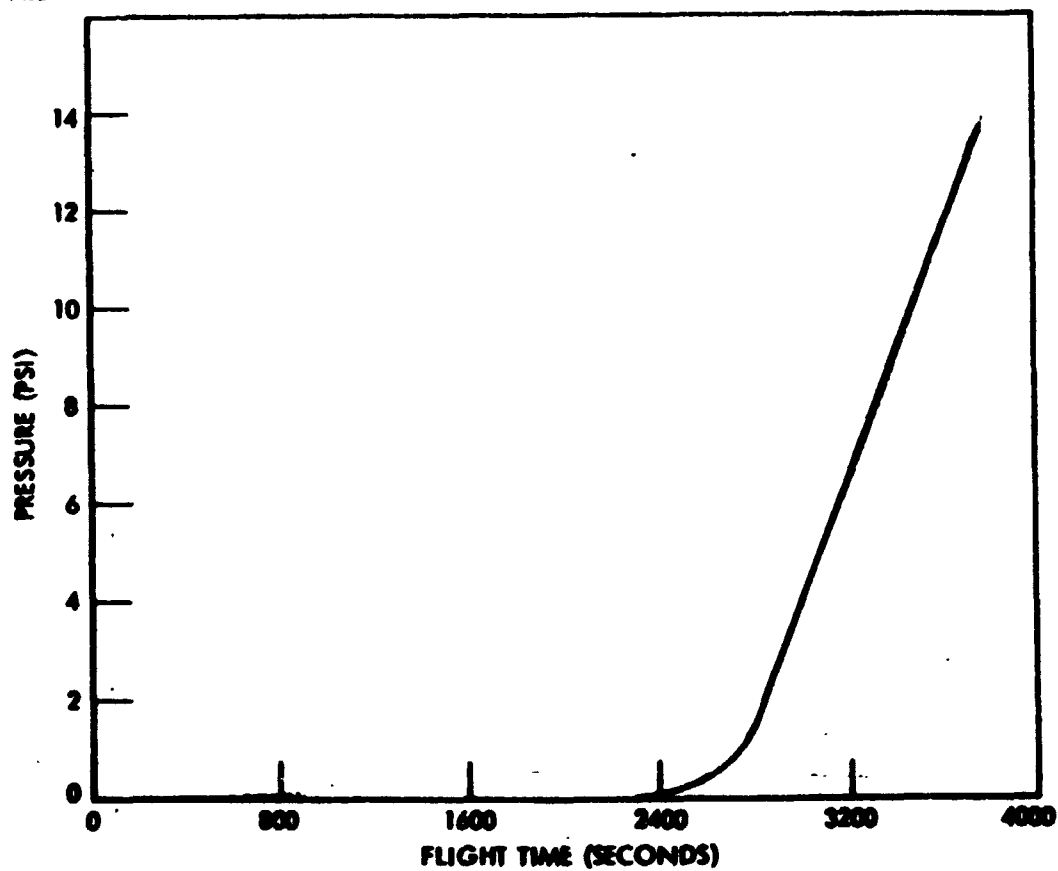


Figure A-2. Cargo Bay Internal Pressure Time History During Reentry



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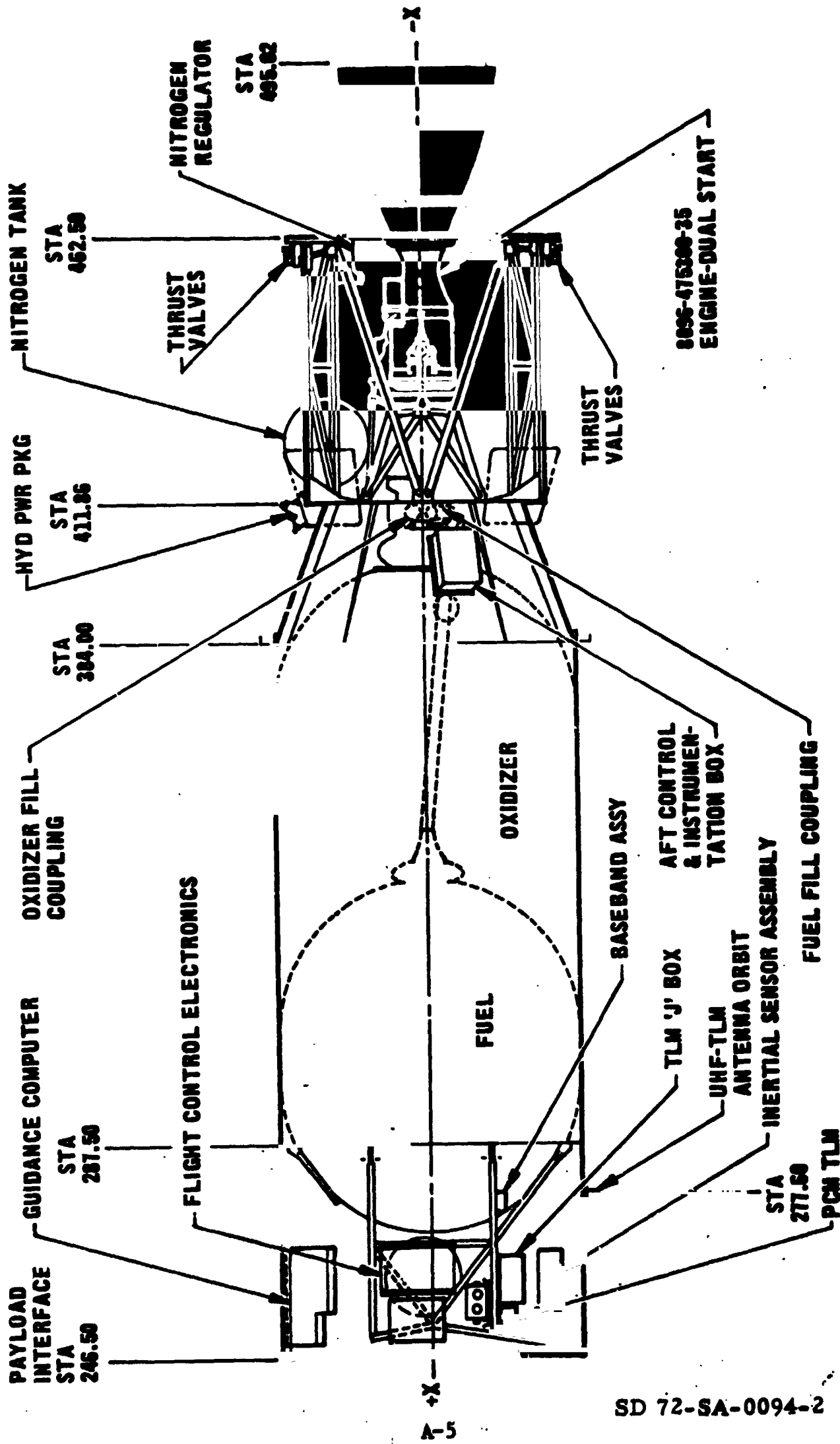


Figure A-3. Agena

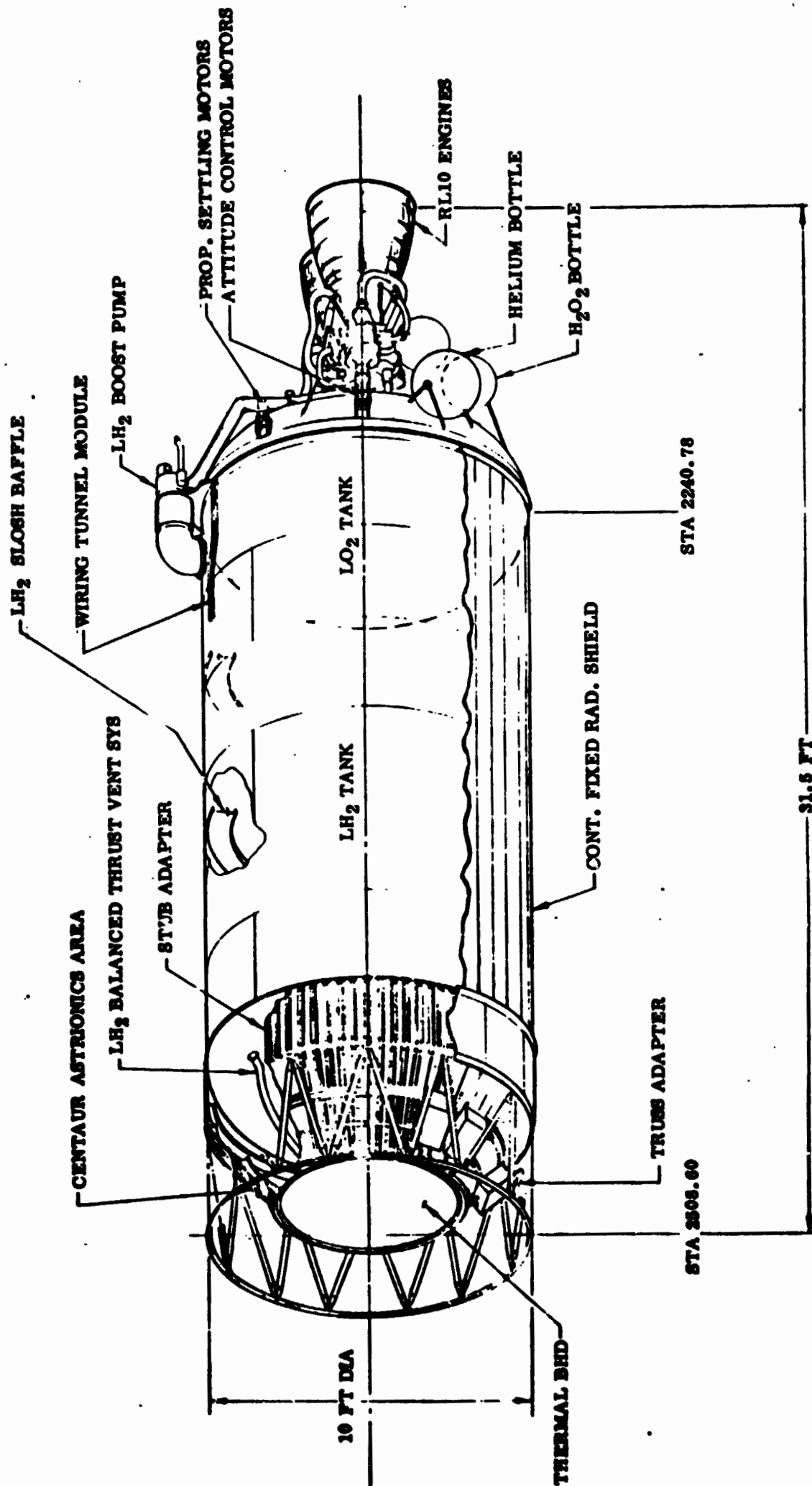


Figure A-4. Centaur



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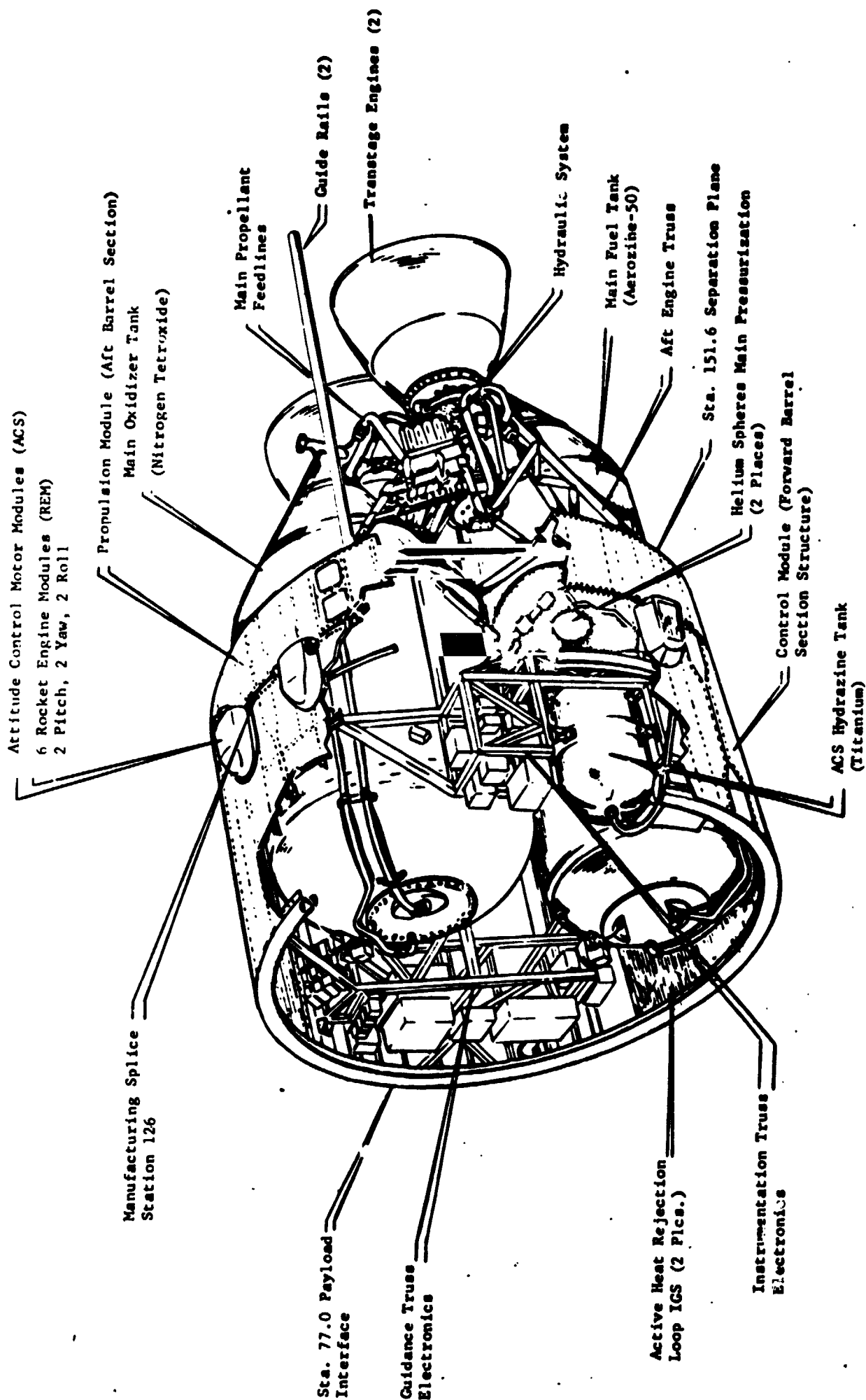


Figure A-5. Transtage



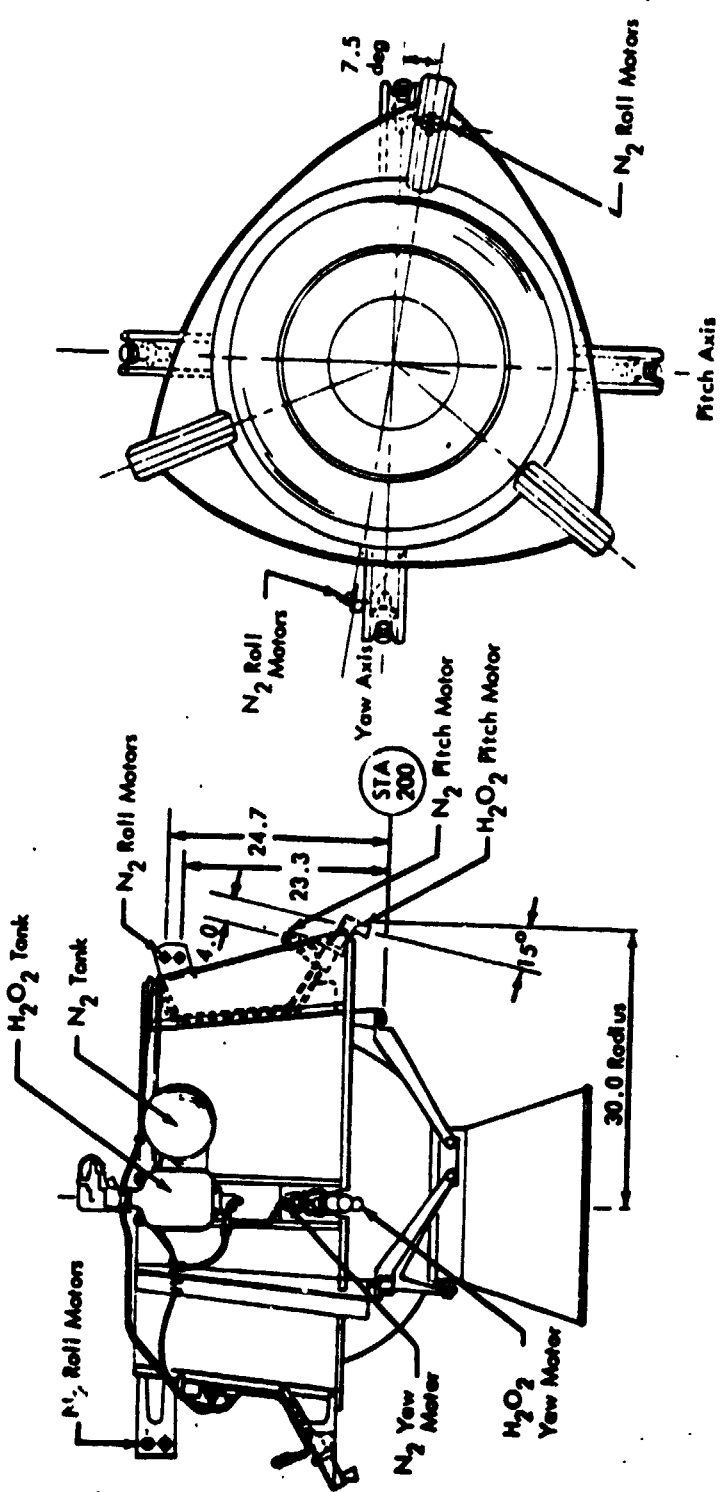
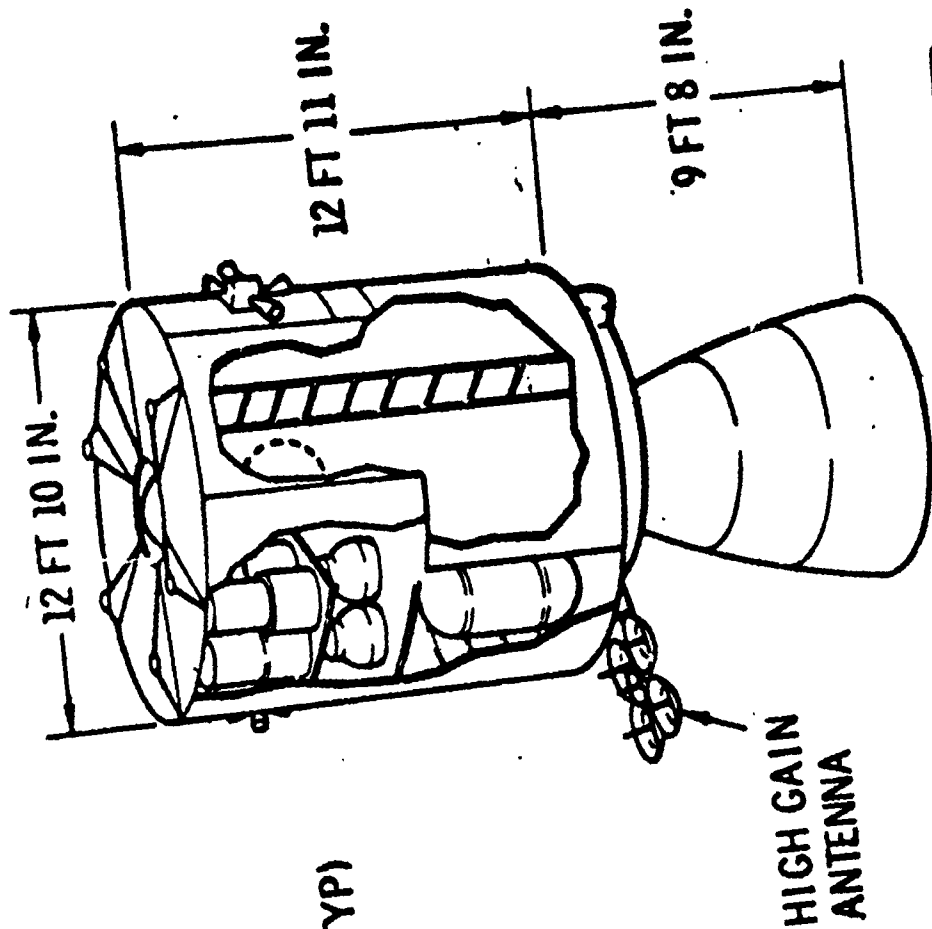
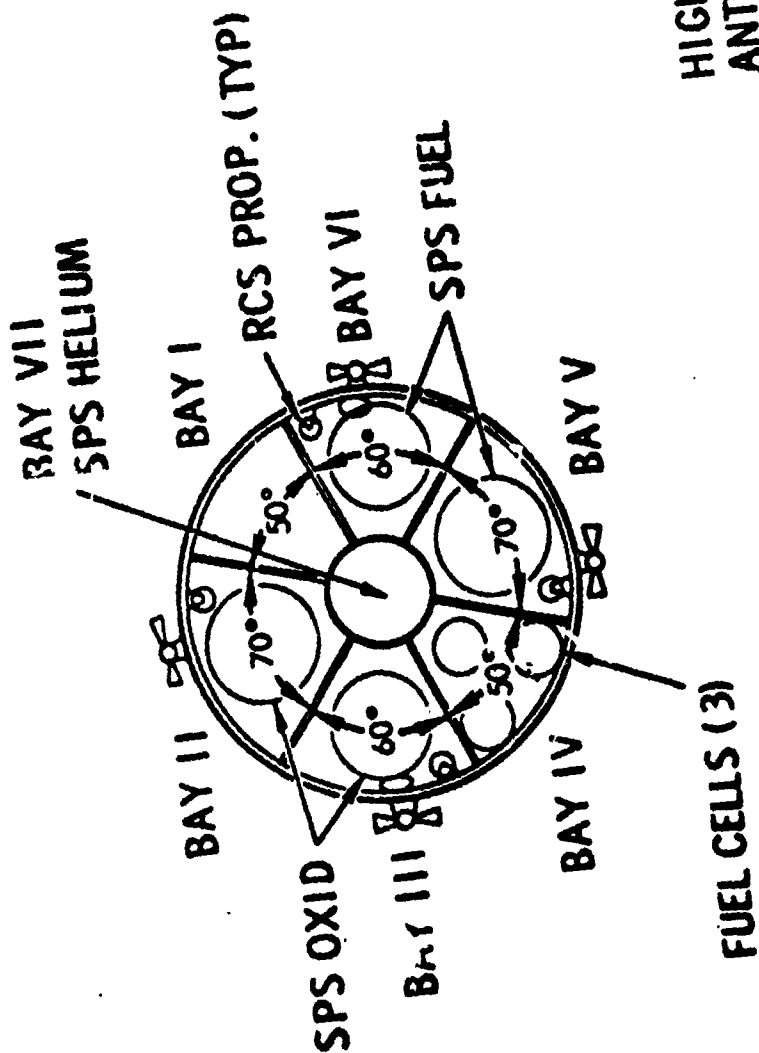


Figure A-6. Burner II



BAYS	VOLUME (EACH) FT <sup>3</sup>
I, IV	200
II, V	264
III, VI	232
VII	135



- 50,200 LB MAX GROSS WT
- 10,200 LB BURNOUT WT
- 20K LB THRUST, 314.5 SEC ISP
- ELECT. POWER, COMMUNICATION ANT.
- ENVIRONMENTAL CONTROL
- STABILIZATION CONTROL - RCS

Figure A-7. Apollo Service Module

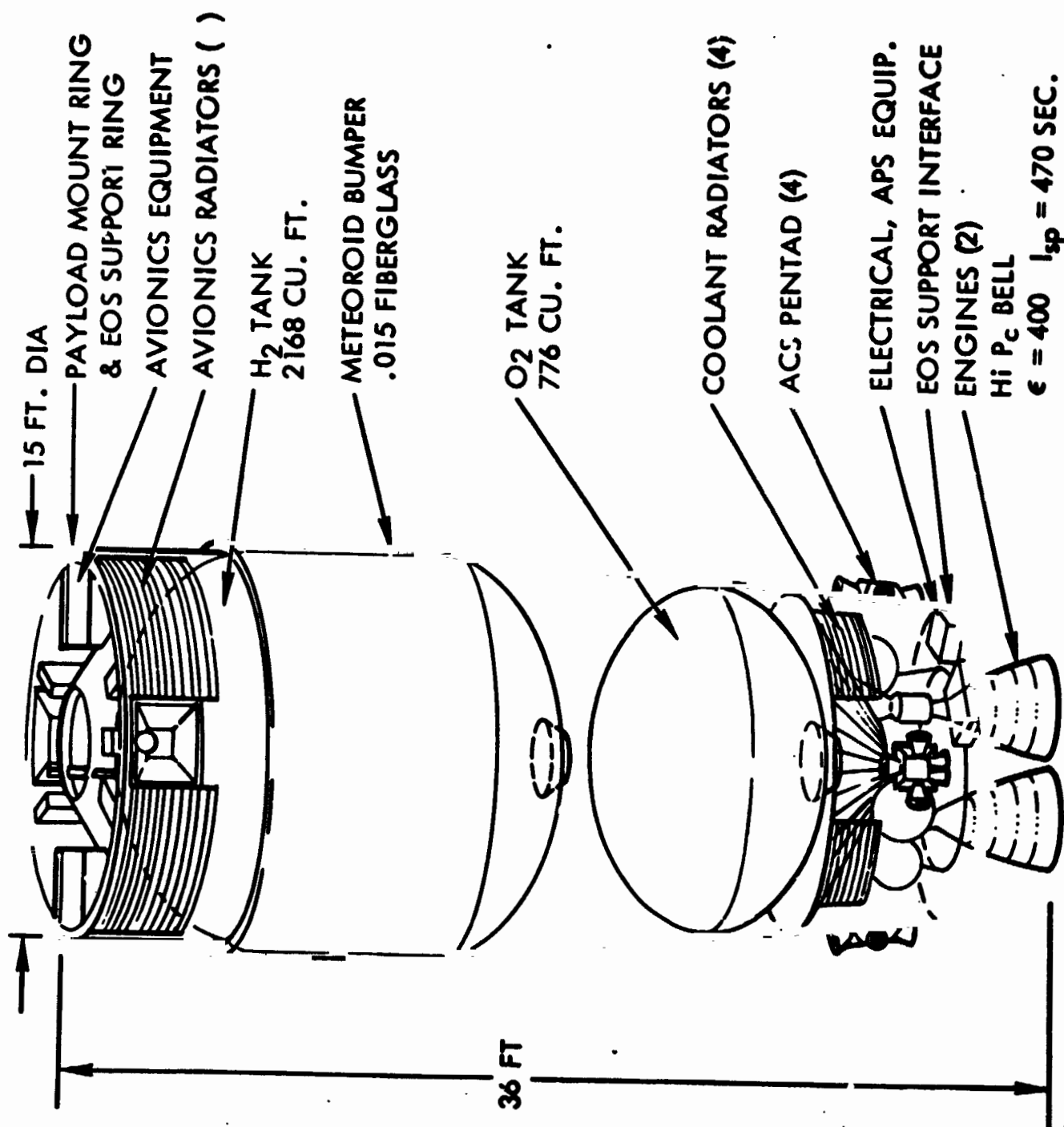


Figure A-8. Tug or Orbit-to-Orbit Shuttle

Primary orbiter operations as related to the deployment and retrieval of upper stage vehicles are shown in Table A-3. The operations, which are listed in the order in which they occur in the mission, were used as a baseline to establish identification of hazardous operations associated with upper stage vehicles as orbiter payloads.

Table A-3. Typical Operations for Orbiter Deployment and Retrieval of Upper Stage Vehicles

DEPLOYMENT
<p>Maintain orbiter attitude control.</p> <p>Mate deployment mechanism to upper stage vehicle.</p> <p>Release upper stage vehicle from cargo bay attach points.</p> <p>Extend upper stage vehicle out of cargo bay.</p> <p>Perform checkout to verify payload integrity for free flight (G&amp;C, RCS, electrical, propulsion, R.F. Communications, etc.).</p> <p>Perform upper stage vehicle separation from deployment mechanism attach points and all other mechanical, electrical, fluid, and hardline instrumentation interfaces.</p> <p>Damp orbiter separation transients.</p> <p>Damp upper stage vehicle separation transients.</p> <p>Maneuver upper stage vehicle to safe separation distance from orbiter.</p> <p>Perform upper stage vehicle burn and completion of mission</p>
RETRIEVAL
<p>Achieve and maintain adjacent station keeping position between the orbiter and upper stage vehicle.</p> <p>Maintain upper stage vehicle attitude control.</p> <p>Maintain orbiter attitude control</p> <p>Extend capture mechanism from cargo bay.</p> <p>Mate capture mechanism with upper stage vehicle.</p> <p>Damp mating transients.</p> <p>De-activate upper stage vehicle attitude control.</p> <p>Dump upper stage vehicle propellants and pressurants.</p> <p>Retract upper stage vehicle into cargo bay.</p> <p>Secure upper stage vehicle to cargo bay attach points.</p> <p>De-mate capture mechanism from upper stage vehicle and stow in cargo bay.</p> <p>Close cargo bay doors.</p>



Potential hazards were identified by considering the hazardous elements of each upper stage vehicle (Section 4.1.2.2) and potential failure modes as applicable to each operation (Section 4.1.2.3). These potential hazards are listed for each upper stage vehicle in Tables A-4 to A-8 listed by mission phase. Because of lack of detailed hardware definition, hazards for the OSS/Tug have not been identified in this detail, but the Centaur hazards may be regarded as typical of the OSS/Tug.

Table A-4. Agena/Orbiter Hazards

1. Transport in the shuttle bay while in parking orbit.
  - 1.1 Helium tank or line explosion.
  - 1.2 Nitrogen tank or line explosion.
  - 1.3 Premature pyrotechnic initiation.
    - 1.3.1 Helium valve(s).
    - 1.3.2 Turbine start solid propellant charge(s).
    - 1.3.3 Destruct charge (if required).
    - 1.3.4 Secondary translation solid rockets (if required).
    - 1.3.5 Payload separation pyrotechnics.
    - 1.3.6 Forward structure skin panel separation.
  - 1.4 Oxidizer leak - Corrosive fluid into closed cargo bay.
    - 1.4.1 Tank.
    - 1.4.2 Rocket engine start valve.
    - 1.4.3 Vent valve.
    - 1.4.4 Piping.
    - 1.4.5 Fill valve.
    - 1.4.6 Gas generator valve.
  - 1.5 Fuel leak - Corrosive fluid into closed cargo bay.
    - 1.5.1 Tank.
    - 1.5.2 Rocket engine start valve.
    - 1.5.3 Vent valve.
    - 1.5.4 Piping
    - 1.5.5 Fill valve
    - 1.5.6 Gas generator valve.
  - 1.6 Inadvertent start.
    - 1.6.1 Signal.
    - 1.6.2 Gas generator valve opens.
  - 1.7 Inadvertent Agena separation from EOJ.
    - 1.7.1 One attachment point separated.
    - 1.7.2 Two attachment points separated.
    - 1.7.3 All attachment points separated.

Table A-4. Agena/Orbiter Hazards (Continued)

1.8 Inadvertent satellite separation from Agena.

1.8.1 Agena structure failure.

1.8.2 Signal sent in error.

2. During shuttle boost to higher orbit.

2.1 thru 2.6 same as 1.1 thru 1.8.

2.9 Support structure failure.

-Transition piece failure between Agena circular ring and EOS hard points.

3. In the higher orbit.

3.1 thru 3.8 same as 1.1 thru 1.8.

4. While being prepared for deployment.

4.1 thru 4.8 same as 1.1 thru 1.8.

5. During deployment and release.

5.1 Deployment

5.1.1 thru 5.1.3 same as 1.1 thru 1.3.

5.1.4 thru 5.1.6 same as 1.6 thru 1.8.

5.1.7 same as 2.9.

5.2 Release

5.2.1 thru 5.2.3 same as 1.1 thru 1.3

5.2.4 same as 1.6.

5.2.5 same as 1.8.

5.2.6 Gas jet thruster failed "on" - pitch jet #2 or 5.

5.2.7 Directed helium leak sufficient to over-power the gas jets.

5.2.7.1 Tank.

5.2.7.2 Helium start valve.

5.2.7.3 Helium fill valve.

5.2.8 Directed nitrogen leak sufficient to overpower the gas jets.

5.2.8.1 Tank.

5.2.8.2 N<sub>2</sub> start valve.

5.2.8.3 N<sub>2</sub> fill valve.

B

**Table A-4. Agena/Orbiter Hazards (Continued)**

5.2.9 Directed oxidizer leak sufficient to over-power the gas jets.
5.2.9.1 thru 5.2.9.6 same as 1.4.1 thru 1.4.6.
5.2.10 Directed fuel leak sufficient to over-power the gas jets.
5.2.10.1 thru 5.2.10.6 same as 1.5.1 thru 1.5.6.
5.2.11 No separation.
5.2.11.1 All separation points successful except 1.
5.2.11.2 No separation points successful.
5.2.12 Failure of critical functions.
5.2.12.1 Electrical power.
5.2.12.2 Gas jets.
5.2.12.3 Stabilization control.
6. During retrieval. - No applicable.
7. During parking orbit until de-orbit.- Not applicable.
8. During and following an aborted shuttle mission at any of the above stages.
8.1 Abort not related to payload.
8.1.1 Agena and satellite too heavy for EOS return, reentry, or landing.
8.2 Abort because of hazard or failure in payload.
8.2.1 Damage to Agena or EOS preventing deployment and release.
8.2.1.1 thru 8.2.1.8 same as 1.1 thru 1.8.

Table A-5. Centaur/Orbiter Hazards

1. Transport in the shuttle bay while in parking orbit.
  - 1.1 Helium tank or line explosion.
  - 1.2 Hydrogen peroxide tank or line explosion.
  - 1.3 Premature pyrotechnic initiation.
    - 1.3.1 Centaur insulation panels shaped charges.
    - 1.3.2 Command destruct shaped charge.
    - 1.3.3 Centaur attachments to EOS and payload, if required.
      - 1.3.3.1 Centaur/EOS adapter.
      - 1.3.3.2 Centaur/payload separation.
  - 1.4 Oxidizer leak - Excessive fluid into partially closed cargo bay.
    - 1.4.1 Tank.
    - 1.4.2 Oxidizer inlet shutoff valve - internal and external.
    - 1.4.3 Fill and drain valve.
    - 1.4.4 Boost pump - external.
    - 1.4.5 Piping - many fittings.
    - 1.4.6 Vent valve.
  - 1.5 Fuel leak - excessive fluid into partially closed cargo bay.
    - 1.5.1 Tank.
    - 1.5.2 Fuel inlet shutoff valve - external.
    - 1.5.3 Fill and drain valve.
    - 1.5.4 Boost pump - external.
    - 1.5.5 Piping - many fittings.
    - 1.5.6 Vent valve.
  - 1.6 Inadvertent start.
    - 1.6.1 Without ignition.
      - 1.6.1.1 Excessive fluid into partially closed cargo bay.
      - 1.6.1.2 Explosive atmosphere around electrical disconnects.
    - 1.6.2 With ignition.
      - 1.6.2.1 Combustion gases into partially closed cargo bay.
      - 1.6.2.2 Combustion gas impingement on critical EOS components.
    - 1.6.3 H<sub>2</sub>O<sub>2</sub> initiation only.
      - 1.6.3.1 H<sub>2</sub> boost pump.
      - 1.6.3.2 O<sub>2</sub> boost pump.
  - 1.7 Inadvertent activation of RCS thruster(s).

-Any thruster or combination of thrusters.

    - 1.7.1 Release of hot gas into partially closed cargo bay.
    - 1.7.2 Impingement of hot gas on cargo bay wall.





Table A-5. Centaur/Orbiter Hazards (Continued)

- 1.8  $H_2O_2$  leak - catalytic decomposition of  $H_2O_2$  liquid or vapor on incompatible materials;; e.g.,
  - 1.8.1 RCS thruster valves (14).
  - 1.8.2 Tank.
  - 1.8.3 Piping.
- 1.9 Inadvertent Centaur separation from EOS.
  - 1.9.1 Activation of any one of three attachment points.
- 1.10 Inadvertent satellite separation from Centaur.
  - 1.10.1 Signal sent in error.
- 1.11 Imbalance of pressure in main propellant tanks - potential rupture of common bulkhead and mixing of propellants into an explosive combination.
- 1.12 Overboard line separation - configuration for minimum EOS impact is ground tanked.
  - 1.12.1 Hydrogen vent lines (2).
  - 1.12.2 Hydrogen fill and drain line.
  - 1.13.3 Oxygen fill and drain line.
  - 1.12.4 Oxygen vent line.
- 1.13 Helium regulator for oxidizer tank pressurization failed open.
- 1.14 Helium regulator for fuel tank pressurization failed open.
- 2. During shuttle boost into higher orbit.
  - 2.1 thru 2.14 same as 1.1 thru 1.14.
  - 2.2 Structural failure of any one of three attachment points.
- 3. In the higher orbit.
  - 3.1 thru 3.14 same as 1.1 thru 1.14.
- 4. While being prepared for deployment.
  - 4.1 thru 4.14 same as 1.1 thru 1.14
- 5. During deployment and release.
  - 5.1 Deployment
    - 5.1.1 thru 5.1.3 same as 1.1 thru 1.3
    - 5.1.4 same as 1.6.2.
    - 5.1.5 thru 5.1.7 same as 1.9 thru 1.11.



Table A-5. Centaur/Orbiter Hazards (Continued)

- 5.1.8 and 5.1.9 same as 1.13 and 1.14.
- 5.1.10 Structural failure of Centaur/EOS attachment points.
- 5.1.11 Inability to separate overboard lines and electrical connectors between Centaur and EOS.

5.2 Release.

- 5.2.1 thru 5.2.3 same as 1.1 thru 1.3
- 5.2.4 same as 1.6.2.
- 5.2.5 same as 1.11.
- 5.2.6 and 5.2.7 same as 1.13 and 1.14.
- 5.2.8 Gas jet thrusters started "on".

- 5.2.8.1 Either pitch jet.
- 5.2.8.2 Any one 50# thruster.

5.2.9 Directed helium leak sufficient to overpower the gas jets.

- 5.2.9.1 Tank(s).
- 5.2.9.2 Fill valve.
- 5.2.9.3 Start valve(s).
- 5.2.9.4 Regulator(s).

5.2.10 Directed oxygen leak sufficient to overpower three gas jets.

- 5.2.10.1 thru 5.2.10.6 same as 1.4.1 thru 1.4.6.

5.2.11 Directed fuel leak sufficient to overpower three gas jets.

- 5.2.11.1 thru 5.2.11.6 same as 1.5.1 thru 1.5.6.

5.2.12 No separation.

5.2.13 Failure of critical function.

- 5.2.13.1 Electrical power.
- 5.2.13.2 Gas jets.
- 5.2.13.3 Stabilization control.

6. During retrieval

6.1 Rendezvous and docking - active rendezvous by EOS and special docking adapter, since Centaur RCS is insufficient to provide translation in all axes.

- 6.1.1 Inability to depressurize main tanks.
- 6.1.2 and 6.1.3 same as 1.1 and 1.2
- 6.1.4  $H_2O_2$  leak sufficient to exhaust the supply.

- 6.1.4.1 thru 6.1.4.3 same as 1.8.1 thru 1.8.3.

Table A-5. Centaur/Orbiter Hazards (Continued)

6.1.5 same as 1.11.
6.1.6 and 6.1.7 same as 1.13 and 1.14.
6.1.8 same as 5.2.13.
6.2 Retrieval into the cargo bay.
6.2.1 Failure to relieve helium pressure and exhaust H <sub>2</sub> O <sub>2</sub> .
6.2.2 same as 2.2
6.2.3 Inability of the cargo bay doors to close due to interference with overboard connection.
7. During parking orbit until de-orbit - no credible hazards.

Table A-6. Transtage/Orbiter Hazards

1. Transport in the shuttle bay while in parking orbit.
1.1 Helium tank or line explosion.
1.2 Nitrogen tank or line explosion.
1.3 Oxidizer leak - corrosive fluid into partially closed cargo bay.
1.3.1 Tank.
1.3.2 Bipropellant valve (2).
1.3.3 Piping.
1.4 Fuel leak - corrosive fluid into partially closed cargo bay.
1.4.1 Tank
1.4.2 Bipropellant valve (2).
1.4.3 Piping.
1.5 Inadvertent start - hot gas impingement on critical shuttle components.
1.5.1 Either or both bipropellant valves opening.
1.5.2 Inadvertent signal to fuel control solenoid.
1.6 Inadvertent separation of Transtage from EOS.
1.7 Inadvertent separation of payload from Transtage.
2. During shuttle boost to higher orbit.
2.1 thru 2.7 same as 1.1 thru 1.7.
2.8 Support structure failure - transition piece between Transtage and EOS support.

Table A-6. Transtage/Orbiter Hazards (Continued)

3. In the higher orbit.

3.1 thru 3.7 same as 1.1 thru 1.7.

4. While being prepared for deployment.

4.1 thru 5.7 same as 1.1 thru 1.7.

5. During deployment and release.

5.1 Deployment

5.1.1 and 5.1.2 same as 1.1 and 1.2.

5.1.3 thru 5.1.5 same as 1.5 thru 1.7.

5.1.6 same as 2.8.

5.2 Release

5.2.1 and 5.2.2 same as 1.1 and 1.2

5.2.3 same as 1.5.

5.2.4 Directed helium leak sufficient to overpower the  
RCS jets.

5.2.4.1 Tank.

5.2.4.2 Piping.

5.2.5 Directed nitrogen leak sufficient to overpower the  
RCS jets.

5.2.5.1 Tank.

5.2.5.2 Piping.

5.2.6 Directed oxidizer leak sufficient to overpower the RCS  
jets.

5.2.6.1 thru 5.2.6.3 same as 1.3.1 thru 1.3.3.

5.2.7 Directed fuel leak sufficient to overpower the RCS jets.

5.2.7.1 thru 5.2.7.3 same as 1.4.1 thru 1.4.3.

5.2.8 Failure of critical functions.

5.2.9.1 Electrical power.

5.2.9.2 RCS engines - explosion or valve started closed.

5.2.9.3 Stabilization control.

6. During retrieval - not applicable

7. During parking orbit until de-orbit - not applicable.

Table A-6. Transtage/Orbiter Hazards (Continued)

- 8. During and following an aborted shuttle mission at any of the above stages.
  - 8.1 Abort not related to Transtage or payload.
    - 8.1.1 Transtage and payload too heavy for EOS return, reentry, or landing.
  - 8.2 Abort because of hazard of failure in Transtage or payload.
    - 8.2.1 thru 8.2.7 same as 1.1 thru 1.7.

Table A-7. Burner 11/Orbiter Hazards

- 1. Transport in the shuttle bay while in parking orbit.
  - 1.1 Nitrogen tank or line explosion.
  - 1.2  $H_2O_2$  tank or line explosion.
  - 1.3 Premature pyrotechnic initiation.
    - 1.3.1 Pyrogen igniter - ignites rocket engine.
      - Hot gas impingement on critical upper stage components.
      - Large volume of hot gas in partially closed cargo bay.
    - 1.3.2 Burner 11 attachment to payload.
      - Releases payload inside cargo bay.
    - 1.3.3 Destruct system, if required.
  - 1.4  $H_2O_2$  leak - corrosive and heat generating liquid released into the cargo bay.
    - 1.4.1 Fill and drain port.
    - 1.4.2 Piping.
    - 1.4.3 Relief valve.
    - 1.4.4 Start valves (4).
  - 1.5  $N_2$  pressure regulator failure in the open position.
    - Overpressurize the downstream piping and  $H_2O_2$  tanks.  
Possible explosion.
  - 1.6 Inadvertent opening of any  $H_2O_2$  start valve - release of hot steam into cargo bay.



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Table A-7. Burner 11/Orbiter Hazards (Continued)

- 1.7 Inadvertent separation of Burner 11 from upper stage vehicle.
- 2. During shuttle boost into higher orbit.
  - 2.1 thru 2.7 same as 1.1 thru 1.7.
  - 2.8 Burner 11 structural failure and separation from payload or upper stage.
- 3. In the higher orbit.
  - 3.1 thru 3.7 same as 1.1 thru 1.7.
- 4. While being prepared for deployment.
  - 4.1 thru 4.7 same as 1.1 thru 1.7.
- 5. During deployment and release.
  - 5.1 Deployment
    - 5.1.1 thru 5.1.3 same as 1.1 thru 1.3
    - 5.1.4 same as 1.5.
    - 5.1.5 same as 1.7.
    - 5.1.6 same as 2.8.
  - 5.2 Release
    - 5.2.1 thru 5.2.3 same as 1.1 thru 1.3.
    - 5.2.4 thru 5.2.6 same as 1.5 thru 1.7.
    - 5.2.7 Inadvertent opening of gas jet start valve.
      - 5.2.7.1 Either pitch jet.
      - 5.2.7.2 Either yaw jet.
      - 5.2.7.3 Any combination of two roll jets.
    - 5.2.8 Directed nitrogen leak sufficient to overpower the gas jets.
      - 5.2.8.1 Tanks (2).
      - 5.2.8.2 High pressure fill port.
      - 5.2.8.3 Pressure regulator.
      - 5.2.8.4 Regulated pressure fill and bleed port.
      - 5.2.8.5 Gas jet start valves (6).
    - 5.2.9 No separation of Burner 11 upper stage assembly from deployment mechanism.
    - 5.2.10 Primary battery failure - loss of attitude control.
      - 5.2.10.1 Overpressure and expulsion of electrolyte.
      - 5.2.10.2 Internal short.
      - 5.2.10.3 Internal open.



Table A-7. Burner 11/Orbiter Hazards (Continued)

- 5.2.11 Primary electrical distribution harness failure - open or short.
- 5.2.12 Gyro inertial reference failure - loss of vehicle orientation control.
- 5.2.13 Programmer failure - loss of control signals.
- 5.2.14 Inverter failure.
- 5.2.15 Flight control electronics failure.
- 6. During retrieval - not applicable.
- 7. During parking orbit until de-orbit - not applicable.
- 8. During and following an aborted shuttle mission at any of the above stages.
  - 8.1 Abort not related to Burner 11 or payload.
    - 8.1.1 Upper stage, Burner 11, and payload too heavy for EOS return, reentry, or landing.
  - 8.2 Abort because of hazard or failure in Burner 11 or payload.
    - 8.2.1 thru 8.2.7 same as 1.1 thru 1.7.

Table A-8. Apollo Service Module/Orbiter Hazards

- 1. Transport in the shuttle bay while in parking orbit.
  - 1.1 Helium tank (6) or line explosion.
  - 1.2 Oxygen tank (2) or line explosion.
  - 1.3 Hydrogen tank or line explosion.
  - 1.4 Premature pyrotechnic initiation.
    - 1.4.1 Antenna deployment.
    - 1.4.2 SM separation from shuttle attachment points.
    - 1.4.3 Payload separation from SM.
  - 1.5  $N_2O_4$  leak - corrosive fluid into partially closed cargo bay.
    - 1.5.1 Tank.
    - 1.5.2 Piping.
    - 1.5.3 Flexible lines.

Table A-8. Apollo Service Module/Orbiter Hazards (Continued)

1.6 A-50 leak - corrosive and heat generating fluid into partially closed cargo bay.

1.6.1 Tank.

1.6.2 Piping.

1.6.3 Flexible lines.

1.7 Inadvertent start - signal.

1.8 Water/glycol leak.

1.8.1 Piping

1.8.2 Radiators.

1.9 Monomethyl hydrazine leak - corrosive fluid.

1.9.1 Tanks (8).

1.9.2 Piping.

2. During shuttle boost to higher orbit.

2.1 thru 2.8 same as 1.1 thru 1.6.

2.9 Structural failure of connection between SM & EOS.

3. In the higher orbit.

3.1 thru 3.9 same as 1.1 thru 1.9.

4. While being prepared for deployment.

4.1 thru 4.9 same as 1.1 thru 1.9.

4.10 Fuel cell explosion.

5. During deployment and release.

5.1 Deployment.

5.1.1 thru 5.1.4 same as 1.1 thru 1.4.

5.1.5 same as 1.7.

5.1.6 same as 2.9.

5.1.7 same as 4.10.

5.2 Release

5.2.1 thru 5.2.4 same as 1.1 thru 1.4.

5.2.5 same as 1.7.

5.2.6 RCS engine explosion.





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Table A-8. Apollo Service Module/Orbiter Hazards (Continued)

5.2.7 Directed helium leak sufficient to overpower the RCS engines - tank.
5.2.8 Directed oxygen leak - tank.
5.2.9 Directed hydrogen leak - tank.
5.2.10 Directed N <sub>2</sub> O <sub>4</sub> leak - tank.
5.2.11 Directed A-50 leak - tank.
5.2.12 Directed MMH leak - tank.
5.2.13 No separation.
5.2.14 Failure of critical functions.
5.2.14.1 Electrical power.
5.2.14.2 Sequential events control.
5.2.14.3 Pyrotechnics.
5.2.14.4 Guidance and control.
5.2.14.5 Reaction control.
5.2.14.6 Structure.
6. During retrieval - not applicable.
7. During parking orbit until de-orbit - not applicable.
8. During and following an aborted shuttle mission at any of the above stages.
8.1 Abort not related to payload - SM and payload too heavy for LOS return, reentry, or landing.
8.2 Abort because of hazard or failure in payload - damage to SM preventing deployment and release.
8.2.1 thru 8.2.9 same as 1.1 thru 1.9.



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Potential causes for the various emergencies have been identified, and are as follows:

A. Potential Causes of Fire in or Near Cargo bay

1. Leakage of flammable fluids, or fluids which present a fire hazard, into a habitable volume.
2. Leakage or venting of flammable fluid near RCS exhaust plume.
3. Leakage or venting of monopropellants which impinge on catalyst source.
4. Simultaneous leakage or venting of mutually reactive fluids.
5. Simultaneous venting of fluids which are mixed, after venting, near RCS exhaust plume.
6. Accidental or inadvertent firing of payload RCS engines.

B. Potential Causes of Explosion in or Near Cargo Bay

1. Rupture of pressure vessel or explosive fluid container or lines.
2. Leakage of explosive fluids or fluids which create an explosion hazard with subsequent ignition into the shuttle cargo bay.
3. Venting of explosive fluid(s) near RCS exhaust plume.
4. Leakage or venting of monopropellants which impinge on a catalyst source.
5. Simultaneous leakage or venting of mutually reactive fluids.
6. Simultaneous venting of fluids which are mixed, after venting, near an RCS exhaust plume.
7. Accidental or inadvertent firing of payload RCS engines, main propulsion engines, and pyrotechnic or other explosive devices.

C. Potential Causes of Exposure of Orbiter Personnel to Toxic Environment

1. Release of a toxic payload fluid into a pressurized volume of the payload, the environment of which is serviced by the orbiter or interfaces with the orbiter environmental control and life support system.
2. Contamination of a pressurized payload environment which interfaces with the orbiter environment control and life support system at some point in the mission after removal from the orbiter cargo bay, such as during deployment and checkout operations.

**D. Potential Causes of Corrosive Environment to Orbiter Equipment**

1. Leakage of corrosive fluid container or plumbing.
2. Venting of corrosive fluids which contact vehicle structure or external subsystem components.
3. Rupture of corrosive fluid container or plumbing.

Flammable fluid hazards can be categorized into five areas:

1. Those fluids which are flammable in the presence of oxygen at specific temperatures and pressures.
2. Those fluids which can act as oxidizing agents and increase the fire hazard by decreasing the ignition temperature, and therefore increase the potential sources of ignition.
3. Those fluids such as monopropellants, which do not require the presence of oxygen to burn, but decompose violently in contact with a solid catalyst under specific conditions of temperature and pressure.
4. Mutually reactive fluids, such as hypergolic bi-propellants, which do not require the presence of oxygen or an ignition source to chemically react and produce high temperatures.
5. Mutually reactive fluids, such as non-hypergolic bi-propellants, which require an ignition source to chemically react and produce high temperatures.

**A.5 FLUID HAZARDS**

The hazards for each fluid identified in Section 2.2.6, Table 2-4 of the main text of this volume, are classified into toxic, flammable, corrosive, and explosive. These characteristics were extrapolated primarily from the third edition of "Dangerous Properties of Industrial Materials" by N. Irving Sax, 1968, Reinhold Book Corporation.

Toxicity is the ability of a chemical to produce injury once it reaches a susceptible site in or near the body. Classes of toxic substances of concern are fumes, mists, vapors, gases, and cryogens. All cryogens are toxic in that severe frostbite "burns" and tissue damage can result from contact with the skin. Toxic fluids were classified into those substances which (1) act as a simple asphyxiant, that is, the gas replaces oxygen until a toxic level due to insufficient oxygen is reached, (2) are toxic at temperatures which are below that required for decomposition, and (3) are toxic before decomposition, but which become extremely toxic when heated to decomposition. The table does not distinguish between the levels of toxicity such as slight, moderate, or severe, nor does it define the effects in terms of acute (short duration, seconds, minutes, hours), chronic (long duration - days, months, years), or exposure media (inhalation, absorption, through skin, intestinal canal, etc.).

Fluids which could be expected to create a corrosive environment for common spacecraft materials are indicated for their potential corrosive effect in an earth environment. Of the oxidizers, oxygen ( $O_2$ ) could be expected to require a relatively long time to produce corrosive damage. Nitrogen oxide (NO) emits corrosive fumes when exposed to water or steam. Nitrogen tetroxide ( $N_2O_4$ ), which is used on the Agena, Transtage, Apollo Service Module and has potential use on future automated payloads, is extremely corrosive and could be expected to be capable of producing structural or equipment damage within seconds after contact. Hydrogen peroxide is highly corrosive in concentrations greater than approximately 40%. Hydrazine ( $N_2H_4$ ) and members of the hydrazine family indicated on the table, A-50 (50% UDMH + 50% hydrazine), and monomethyl hydrazine are corrosive. Hydrazine fuels containing hydrazine nitrate and hydrazine dperchlorate act as acids in hydrazine solutions, and are responsible for higher corrosion rates. Corrosion and toxicity ratings for hydrazine propellants are listed in Table A-9, as obtained from Report SP06R70-F, Space Station Study of Re-Supply/Repair of Monopropellant Subsystems, Final Report, February 1971, prepared by Hamilton Standard for NASA MSFC.

Table A-9. Corrosion and Toxicity Characteristics of Hydrazine Blends

MONOPROPELLANT	CORROSIVE	TOXICITY
(1) Hydrazine	M	M
(2) Monomethyl Hydrazine (MMH)	L-M	M
(3) Unsymmetrical Dimethyl Hydrazine (UDMH)	L	L-M
(4) Aerozine -50 (UDMH + $N_2H_4$ )	L-M	M
(5) MHF-3 (MMH + $N_2H_4$ )	L-M	M
(6) X-Mix (MMH + $N_2H_4$ + $H_2O$ )	L-M	M
(7) BA10-14 (MMH + $N_2H_4$ + $H_2O$ )	M-H	M
(8) Q-Mix (MMH + $N_2H_4$ + $H_2O$ + HN)	M-H	M
(9) MHF-5 (MMH + $N_2H_4$ + HN)	M	M
(10) Hydrazine - Hydrazine Nitrate - Water	H	M
(11) Hydrazine - Hydrazine Dperchlorate - Water	H	M
(12) Hydrazine - Hydrazine Azide - Water	M	M
(13) Hydrazine - Methoxamine Nitrate	M-H	M
H = High M = Moderate L = Low		

Explosive fluid hazards can be categorized into three areas:

- (1) Those fluids which are explosive in the presence of oxygen at specific temperatures and pressures.
- (2) Those fluids which can act as oxidizing agents and increase the explosion hazard by decreasing the ignition temperature and therefore increase the potential sources of ignition while at the same time increase detonation rates.
- (3) Those fluids which are hazardous because when heated, shocked, or contaminated, the concentrated material can explode or start fires.

It is significant to note that hydrogen peroxide falls into category (3) above.

#### A.6 PROPERTIES OF PRIMARY PAYLOAD FLUIDS

Common properties of primary fluids to be carried as orbiter payloads in significant quantities are tabulated in metric units (Table A-9) and engineering units (Table A-10). The references under flash point temperatures refer to standard equipment utilized in industry to determine the lowest temperature at which a liquid will give off enough vapor, or near its surface, such that in an intimate mixture of air and a spark of flame, it ignites. LEL refers to Lower Explosive Limit.

#### A.7 COMPRESSED GAS TNT EQUIVALENT

The TNT equivalency of compressed gas is shown in Figure A-9. The equivalency is shown for gas expansion to one atmosphere pressure and to space vacuum. The figure is based on the gas behaving like a perfect gas over the range of pressures and temperatures involved. It is also assumed that the gas expands adiabatically (no heat transfer) and isentropically (maximum energy release). The results should be very good for the one atmosphere case, but some errors can be expected at the highest pressure shown for this case, and for the full range for the vacuum case, because of liquefaction and solidification of the gas at the extremely low temperatures it expands to.

The largest anticipated usage of compressed gas for shuttle payloads is expected to be associated with upper stage vehicles requiring propellant system pressurization gases, and with Space Station modules which require atmospheric pressurization and re-pressurization gases. The Centaur, for example, may require as an energy source in an emergency propellant dump system 5 helium pressure vessels at  $2.1 \times 10^7$  N/m<sup>2</sup> (3000 psi), with each tank having an internal volume capacity of 0.168m<sup>3</sup> (6 ft<sup>3</sup>). The TNT equivalent per tank is 2.73 kg (6 lb).

The Apollo Service Module contains two 1m (40 inch) diameter helium tanks capable of storing 0.54m<sup>3</sup> (19.4 ft<sup>3</sup>) of gas each at  $2.75 \times 10^7$  N/m<sup>2</sup> 4000 psi. Each tank has the equivalent of approximately 12.4 kg (27.2 lb) TNT if loaded to capacity.



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Table A-9. Properties of Primary Payload Fluids - Metric Units

PROPERTY \ FLUID	He	H <sub>2</sub> (para)	N <sub>2</sub>	O <sub>2</sub>	UDMH	N <sub>2</sub> O <sub>4</sub>	MMH	H <sub>2</sub> O <sub>2</sub> 98%	N <sub>2</sub> H <sub>4</sub>
Critical Temperature °C	-268.0	-240	-147	-118.4	250	158.2	312	457	380
Critical Pressure N/M <sup>2</sup>	2.29x10 <sup>5</sup>	1.30x10 <sup>6</sup>	3.40x10 <sup>5</sup>	5.09x10 <sup>6</sup>	5.42x10 <sup>6</sup>	1.013x10 <sup>7</sup>	8.24x10 <sup>6</sup>	2.158x10 <sup>7</sup>	1.47x10 <sup>7</sup>
Boiling Point °C	-268.9	-253	-195.5	-183.0	63	21.15	87.5	150.2	113.5
Freezing Point °C	-272	-259	-215	-218.3	-57.2	-12.2	-52.5	0.43	1.5
Heat of Fusion *	---	14.0	6.09	3.30	40.1	32.3 to 37.2	54.1	74.1	94.5
Heat of Vaporization *	6	108	47.6	50.9	139.4	93.4	210	---	334
Auto Ignition T °C	NA	579	NA	---	250	---	194	---	270
Flammability Range in Air	NA	3.2 to 60 g/m <sup>3</sup> at 20 °C	NA	---	2(LEL) to 90% by V at amb.T	---	2.5(LEL) to 98% at 1 atmos.	---	4.7(LEL) to 100% by V at 100%
Flash Point, Open Cup °C	NA	---	NA	---	-15	---	17.2	---	52.0
Flash Point, Closed Cup °C	NA	---	NA	---	1.1	---	21.1	---	37.8
Vapor Pressure N/M <sup>2</sup> at °C	---	1.31x10 <sup>4</sup> at -258	1.38x10 <sup>5</sup> at -193.3	2.55x10 <sup>5</sup> at -133	2.07x10 <sup>3</sup> at -17.8	3.31x10 <sup>4</sup> at 1.1	2.14x10 <sup>3</sup> at 4.4	2.07x10 <sup>2</sup> at 20	4.83x10 <sup>2</sup> at 4.4
	---	1.01x10 <sup>5</sup> at -253	3.58x10 <sup>5</sup> at -183.3	1.15x10 <sup>6</sup> at -151	6.90x10 <sup>3</sup> at 4.4	1.01x10 <sup>5</sup> at 21.1	6.9x10 <sup>3</sup> at 26.7	6.89x10 <sup>2</sup> at 40	2.14x10 <sup>3</sup> at 26.7
	---	1.63x10 <sup>5</sup> at -251	7.79x10 <sup>5</sup> at -173.3	3.39x10 <sup>6</sup> at -129	2.14x10 <sup>4</sup> at 26.7	2.66x10 <sup>5</sup> at 43.3	2.14x10 <sup>4</sup> at 48.9	2.28x10 <sup>3</sup> at 60	7.17x10 <sup>3</sup> at 48.9
	---	8.27x10 <sup>5</sup> at -243	1.48x10 <sup>6</sup> at -163.3	4.24x10 <sup>6</sup> at -123	5.80x10 <sup>4</sup> at 48.9	5.27x10 <sup>5</sup> at 65.6	5.45x10 <sup>4</sup> at 71.1	6.41x10 <sup>3</sup> at 80	2.0x10 <sup>4</sup> at 71.1
	---	1.12x10 <sup>6</sup> at -241	---	---	---	---	---	---	---

\* Calories per gram

Table A-10. Properties of Primary Payload Fluids - Engineering Units

PROPERTY \ FLUID	He	H <sub>2</sub> (para)	N <sub>2</sub>	O <sub>2</sub>	UDMH	N <sub>2</sub> O <sub>4</sub>	MMH	H <sub>2</sub> O <sub>2</sub> 98%	N <sub>2</sub> H <sub>4</sub>
Critical Temperature °F	-450.3	-400	-232.5	-181.1	482	316.8	593.6	855	716
Critical Pressure psia	33.2	188	493	737	786	1469.0	1194	3130	2135
Boiling Point °F	-452	-423	-320	-297.4	146	70.1	189.5	302.4	236.3
Freezing Point °F	-457.8	-435	-346	-361	-71	11.8	-62.5	31.2	35
Heat of Fusion btd/lb	---	25.2	10.962	5.94	72.18	58.14 to 66.96	97.38	133.38	170.1
Heat of Vaporization btu/lb	10.8	194.4	85.68	91.62	250.92	168.12	378	---	601.2
Auto Ignition T °F	NA	1075	NA	---	482	---	382	---	518
Flammability Range in Air	NA	4 to 75% by Vol. at 68°F	NA	---	2(LEL) to 90% by Vol. at ambient	---	2.5 (LEL) to 98% by Vol. in 1 atmos.	---	4.7(LEL) to 100% at 212°F
Flash Point, Open Cup °F	NA	---	NA	---	5	---	63	---	125.6
Flash Point, Closed Cup °F	NA	---	NA	---	34	---	70	---	100
Vapor Pressure psia at °F	---	1.9 at -433	20 at -316	37 at -280	0.3 at 0	4.8 at 30	0.31 at 40	0.03 at 68°F	0.07 at 40
		14.7 at -423	52 at -298	167 at -240	1.0 at 40	14.6 at 70	1.0 at 80	0.10 at 104°F	0.31 at 80
		23.7 at -420	113 at -280	482 at -200	3.1 at 80	38.6 at 110	3.1 at 120	0.33 at 104°F	1.04 at 20
		120 at -405	214 at -262	615 at -190	8.4 at 120	91.0 at 150	7.9 at 160	0.93 at 176°F	2.9 at 100
		162 at -402							



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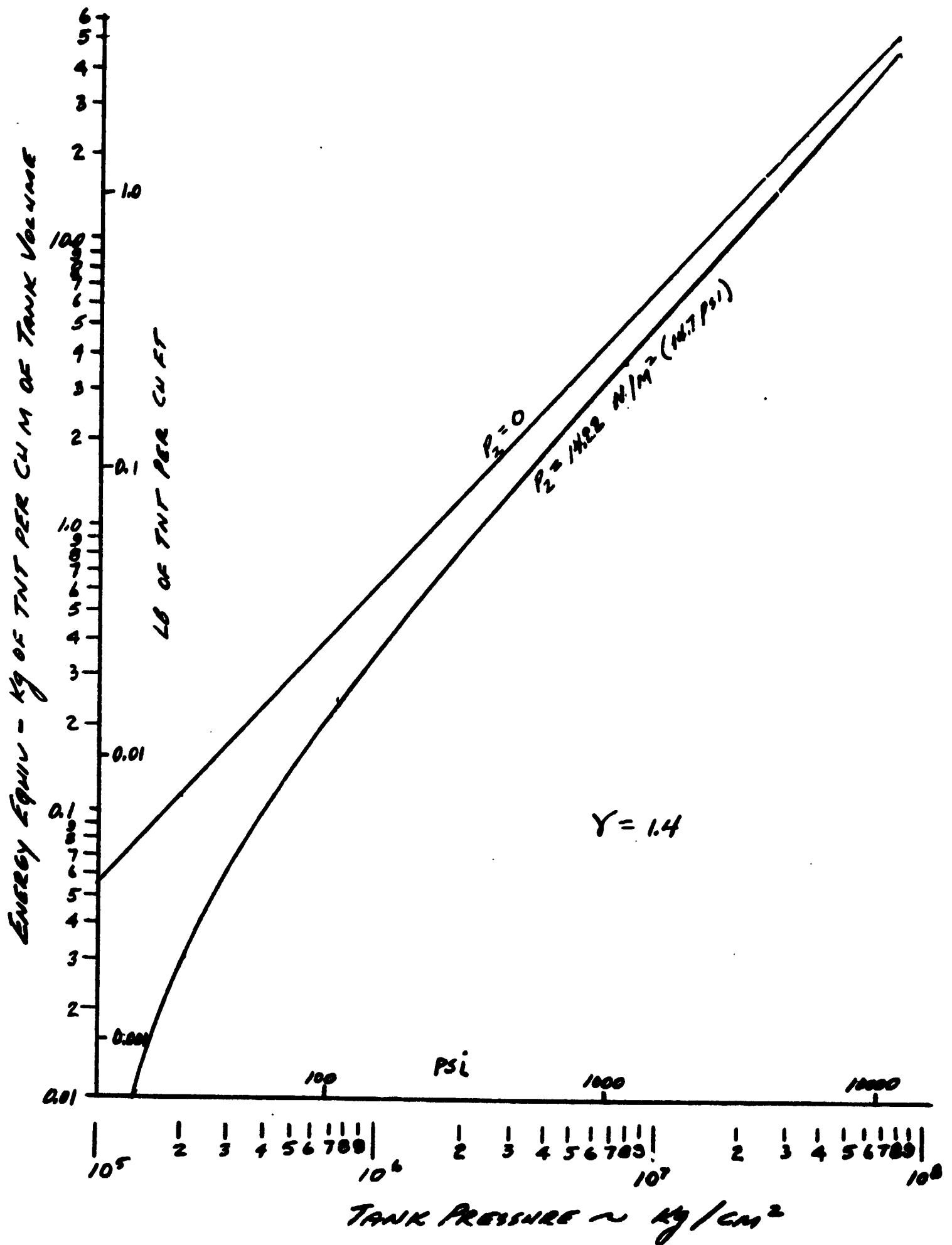


Figure A-9. Compressed Gas TNT Equivalent



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The maximum TNT equivalent of the Modular Space Station pressure vessels is expected to be approximately 5 kg (11 lb), based on 0.84m (33 inch) diameter,  $0.28\text{m}^3$  ( $10\text{ft}^3$ ),  $2.1 \times 10^7\text{ N/m}^2$  (3000 psi) tanks.

A  $141\text{ m}^3$  ( $5000\text{ ft}^3$ ) payload module, such as a space station module, pressurized at 1 atmosphere, possesses a TNT equivalent of 10.3 kg (22.5 lb) while the TNT equivalent for the same volume is reduced to approximately 1.64 kg (3.6 lb) at  $13,800\text{ N/m}^2$  (2 psi).

The above maximum TNT equivalents are expected to represent reasonable upper bounds for orbiter pressure vessel payloads.

#### A.8 CRYOGENIC FLUID TNT EQUIVALENT

In order to determine the TNT equivalent of cryogenic fluids, an analysis was made of how cryogenic fluids behave when they expand into a low or zero pressure environment.

Cryogenic fluids are generally stored as a liquid in a sub-critical state, where a liquid and gas phase can exist together in equilibrium, or in a supercritical state, in which the fluid exists in a single uniform phase, with no sharp distinction between gas and liquid. The supercritical phase is generally characterized by much larger storage pressures.

The analysis indicates that if the fluid pressure is suddenly reduced, e.g. as a result of fluid leakage or tank rupture, the fluid expands and cools, going into a two-phase gas-and-liquid state. If this mixture is confined, as in a cargo bay, so that the gas and liquid can interact and remain in equilibrium, the expansion proceeds until the temperature drops to and below the triple point (where gas, liquid and solid can co-exist in equilibrium). Below the triple point, the liquid (most probably in a mist), condenses into the solid form, and if the expansion continues, more and more of the remaining gas is converted into solid. The expansion stops when the liquid/gas or solid/gas mixture fully occupies the containing vessel.

The energy that is released by the expansion and cooling of the fluid is used in accelerating the fluid, both the gas, and the liquid or solid. It is this energy that is available to damage structure and equipment it impinges on, and can be equated to the TNT equivalent. In the limit, when the fluid expands to space, it theoretically can reach absolute zero temperatures and pressure. In this condition it is all in a solid state. This condition also corresponds to maximum energy release.

The freezing time for oxygen, nitrogen, and hydrogen when the fluid liquid drop is exposed to a vacuum near its boiling point is shown in Figure A-10, as a function of drop diameter. The curves were developed from a linear extrapolation of theoretical data developed in "Freezing of Liquids on Sudden Exposure to Vacuum" by John B. Gayle, Carl T. Egger, and James W. Bransford, Journal of Spacecraft and Rockets, Vol 1, No. 3, May/June 1964.

The freezing times for even large drops of 0.1 m (4 ins) diameter range from 0.025 seconds for hydrogen to 0.3 seconds for oxygen. In the event of



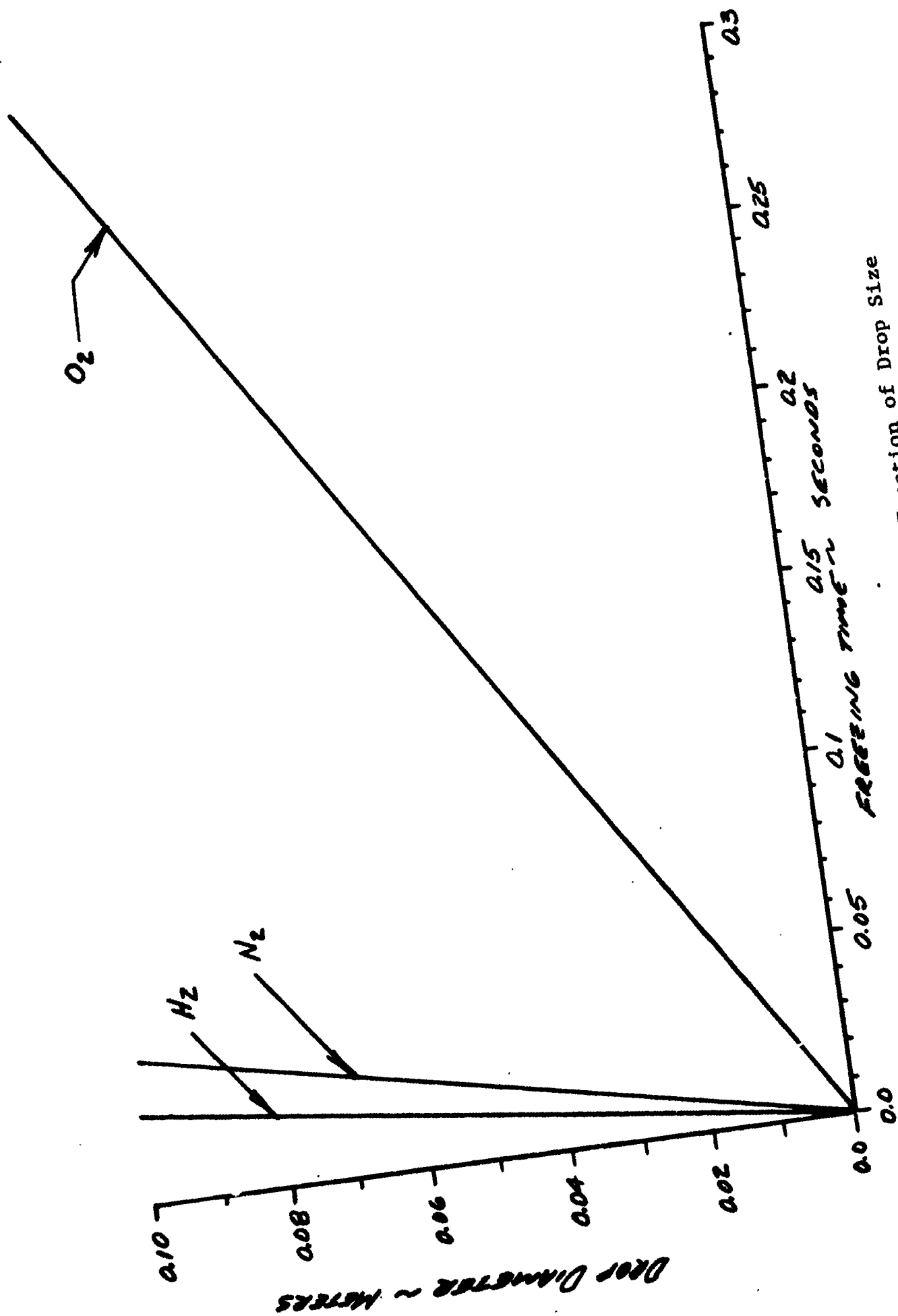


Figure A-10. Freezing Time as a Function of Drop Size

a cryogenic tank rupture, therefore, these times are sufficiently rapid for the energy released during freezing of the fluid to be available to contribute to the TNT equivalent of the cryogenic fluid.

The TNT equivalent of hydrogen (parahydrogen) as it expands from typical subcritical conditions to vacuum is shown in Figure A-11, as being typical of cryogenic fluids. This is plotted against the temperature of the fluid. The initial conditions on the right all represent different combinations of temperature and pressure, with the fluid fully saturated -- i.e., 100% gas for the two top curves, and 100% liquid for the two bottom curves. The four curves are characterized by the entropy, which is assumed to remain constant during expansion. The variation of the corresponding "quality," or proportion of gas, during the expansion is shown for the four curves in Figure A-12.

If the expansion starts or terminates at pressures and temperatures within the range shown in Figure A-13, the TNT equivalent of the expansion is represented by the difference in ordinates for the two points. Since in practice, expansions of interest neither proceed to a vacuum, nor proceed isentropically, it is seen that the curves indicate the maximum potential TNT equivalent (remembering that entropy can only increase during a real process, not decrease).

It is also of interest to note how non-linearly the pressure decreases with the temperature, as shown by the bottom scale of Figure A-11.

Typically, the TNT equivalent of cryogenics is relatively low. As a comparison, Table A-11 compares the TNT equivalent of hydrogen at typical subcritical cryogenic storage conditions as a liquid, with the same temperature and pressure as a gas, and with typical high pressure storage conditions as a gas at room temperature.

Table A-11. TNT Equivalent of Hydrogen Stored at Typical Cryogenic and High Pressure Gas Conditions

Pressure Atm.	Temperature °K (°R)	Phase	TNT Equivalent kg/kg H <sub>2</sub> (lb/lbH <sub>2</sub> )	
			Expanding to 1 Atm.	Expanding to Vacuum
6.8	29 (52)	Liquid	0.006	0.056
6.8	29 (52)	Gas	0.031	0.134
20.4	294 (530)	Gas	0.52	0.75

#### A.9 BLAST OVERPRESSURE

Face and side on overpressures resulting from an explosion are shown in Figure A-13 as a function of blast source TNT equivalent and distance from the source.

The maximum allowable cargo bay pressure for a current NR orbiter design of 13,800 N/m<sup>2</sup> (2 psi) is shown for reference together with the maximum allowable face-on overpressure, 20,700 N/m<sup>2</sup> (3 psi), permissible for personnel exposure without additional protection.

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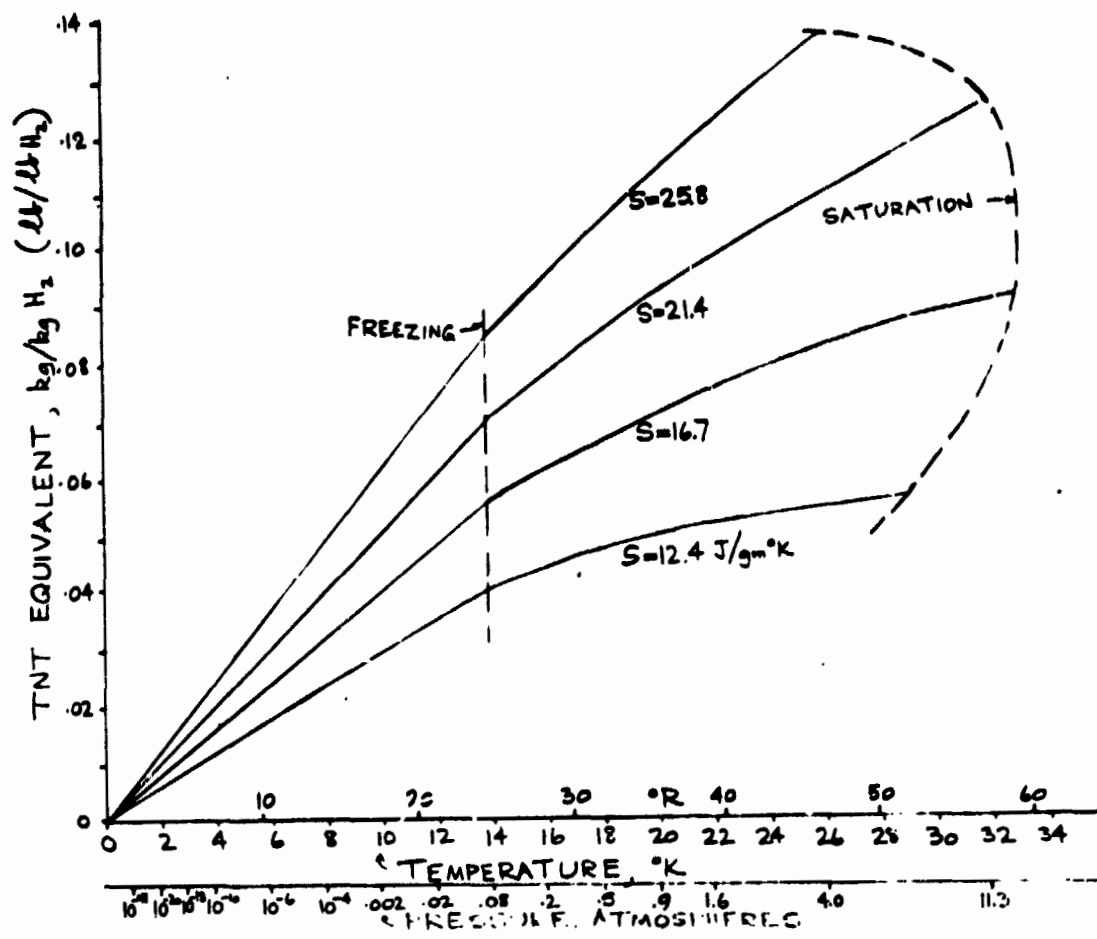


Figure A-11. TNT Equivalent of Cryogenic Hydrogen

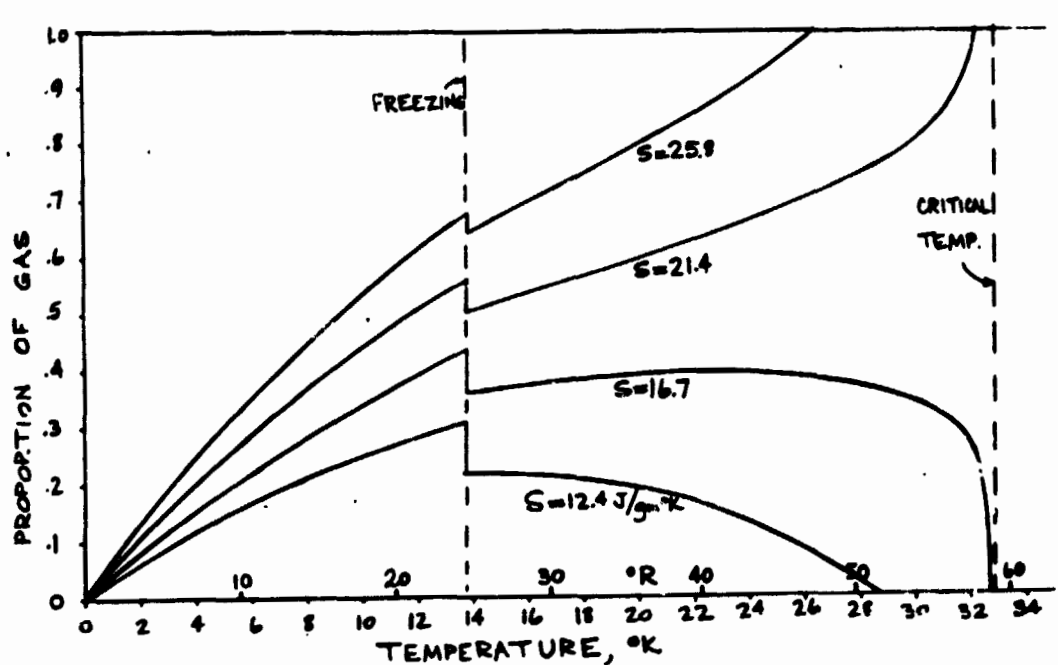


Figure A-12. Freezing Characteristics of Cryogenic Hydrogen

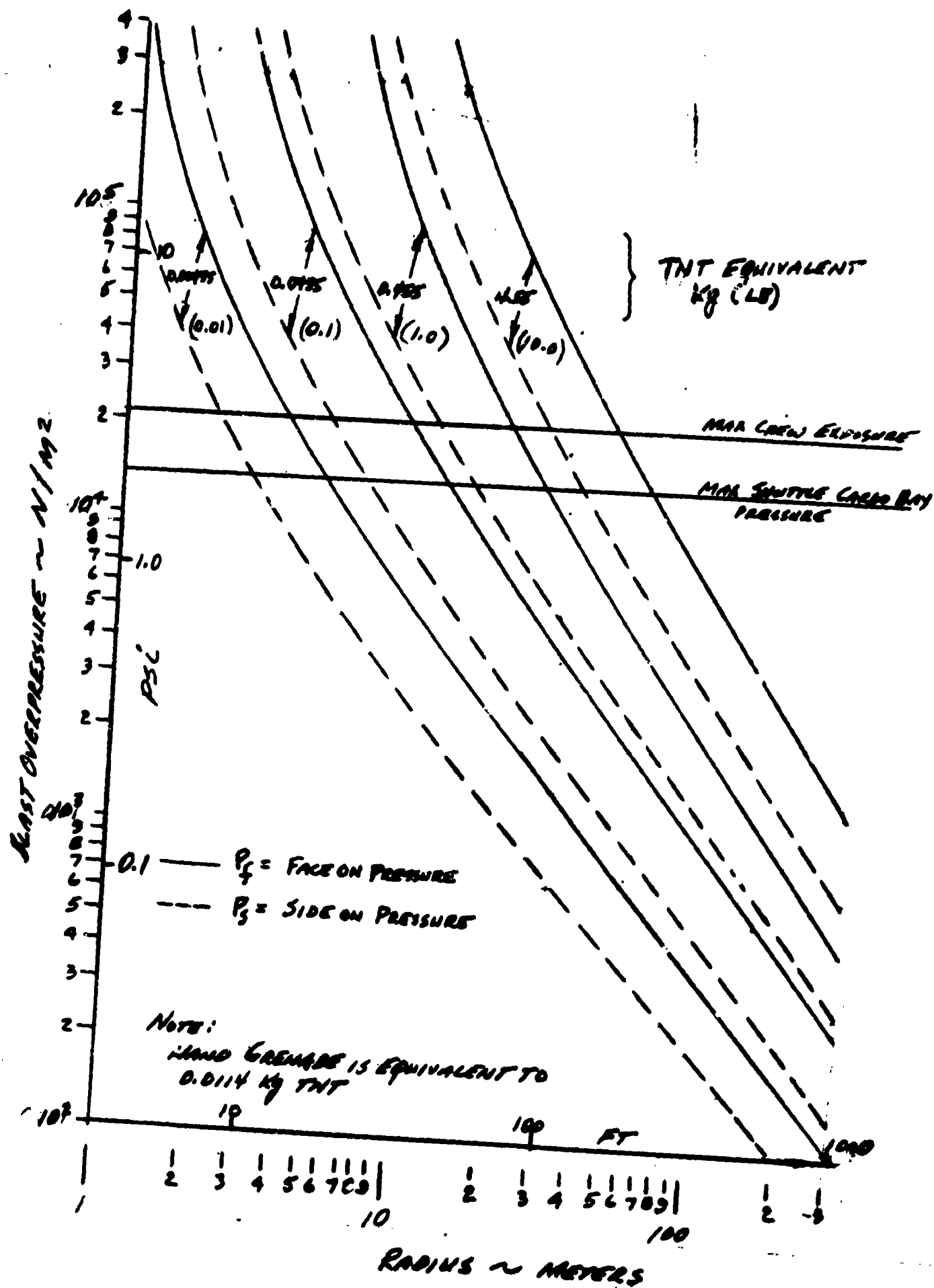


Figure A-13. Blast Overpressures



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The figure shows that considerable cargo bay damage could result from an uncontained explosion within the bay with less than 0.0045 kg (0.01 lb) TNT equivalent. For example, if a blast of this energy equivalent were detonated in the center of a 4.6m (15 ft) diameter x 18.3 m (60 ft) length cargo bay, the structure located at a distance of 2.3 m (7.5 ft) would be exposed to an overpressure in excess of 69,000 N/m<sup>2</sup> (10 psi), while the ends of the bay would be exposed to slightly greater than 6,900 N/m<sup>2</sup> (1 psi).

#### A.10 MAXIMUM TOLERABLE LEAK RATE INTO SHUTTLE CARGO BAY

An investigation was made to determine the maximum allowable leak rate which can be tolerated into the shuttle cargo bay from a pressurized payload vessel. The shuttle cargo bay doors were assumed to be closed and the bay provided with vents to limit cargo bay differential pressures to less than 13,800 N/m<sup>2</sup> (2 psi). A vent area to cargo bay volume ratio of approximately 13.8 cm<sup>2</sup>/m<sup>3</sup> (0.06 in<sup>2</sup>/ft<sup>3</sup>) which has been previously used in NR shuttle venting studies, was assumed to estimate the venting area for any known cargo bay volume.

The maximum tolerable leak rate as a function of vent area, is shown in Figure A-14 and assumes a gas temperature of -205° C (-328° F) (typical temperatures of gases that have leaked into the cargo bay), a maximum allowable cargo bay differential pressure of 13,800 N/m<sup>2</sup> (2 psi), and a discharge coefficient for the vent of 0.85. The leak rate is relatively insensitive to the gas temperature, varying inversely as the square root of the absolute temperature.

It is seen that the maximum leak rate which can be tolerated is larger for gases of high molecular weight than gases of low molecular weight, and that leakage of hydrogen represents the worst case.

Current NR orbiter designs use always-open cargo bay vents of approximately 0.37m<sup>2</sup> (4 ft<sup>2</sup>) area. The maximum tolerable steady state leakage rate into the cargo bay, with doors closed, is of the order of 2.5 kg/sec (5.5 lb/sec) for hydrogen and 20 kg/sec (45 lb/sec) for air, oxygen or nitrogen. Larger leakage rates into the cargo bay can be tolerated for shorter durations, until the cargo bay pressure goes from vacuum to the tolerable limit. Such a large leakage rate for a prolonged period is approaching, in its damaging effects, an explosive rupture of a tank, rather than a leakage.

It can be concluded that overpressurization of the orbiter cargo bay for normal cargo is not a major hazard. It must be considered, however, for payloads containing mostly propellants, such as upper stage vehicles or propellant logistics resupply. The hazard is then serious, however, only during the time the cargo bay doors remain closed.

#### A.11 TOXIC ENVIRONMENT IN THE ORBITER RESULTING FROM CONTAMINATED PRESSURIZED PAYLOAD

The shuttle may be exposed to a toxic environment of a contaminated payload if the orbiter atmosphere, at some point in the mission, such as during orbital maneuvers, deployment, checkout servicing, or cargo handling, interfaces with the payload atmosphere.

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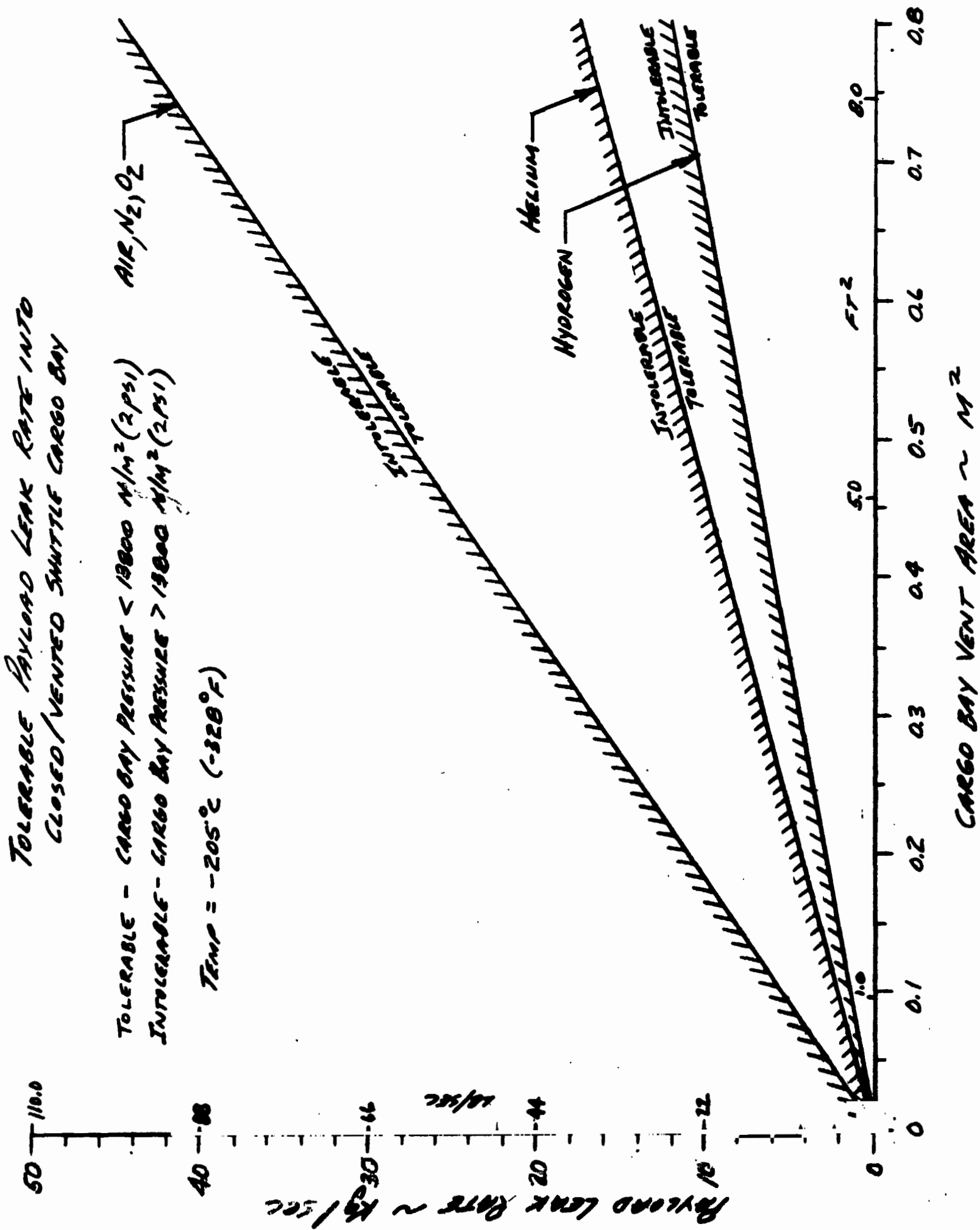


Figure A-14. Tolerable Payload Leak Rate Into Closed/Vented Shuttle Cargo Bay

Eight typical pressurized payload configurations which lead to a toxic orbiter environment are shown in Figure A-15. These are derived from combinations of manned payloads, unmanned payloads, payloads requiring shuttle environmental control, payloads including self-contained environmental control, and pressurized payloads not requiring environmental control. Payload configurations 1, 3 and 6 could present a toxicity hazard to the orbiter during normal operations, since they require a direct interface with the orbiter environment. The remaining configurations could present a toxicity hazard during a contingency situation in which it becomes desirable or necessary to perform an internal visual inspection of the payload.

#### A.12 TESTING POTENTIALLY TOXIC CARGO FOR TOXICITY


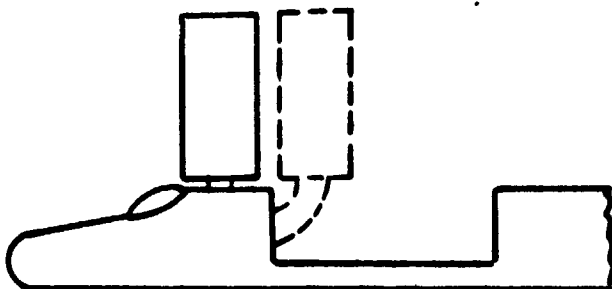
Exposure of on-orbit personnel to a toxic environment could result upon opening of a modularized or equivalent cargo container, the atmosphere of which has been contaminated by breakage or leakage of internal vessels containing a toxic substance. The vessel breakage or leakage could have occurred during ground cargo transfer and handling operations, shuttle ascent to orbit, orbital and docking operations, and on-orbit cargo handling operations.

Examples of toxic fluids which may be delivered to orbit to support experiment operations are carbon tetrafluoride ( $\text{CF}_4$ ), carbon monoxide ( $\text{CO}$ ), mercury, formaldehyde, and nitrogen tetroxide ( $\text{N}_2\text{O}_4$ ). Examples of other toxic substances are bio-organisms, and experiment sensors such as imaging tubes which can release poisonous gases if broken.

Testing potentially toxic cargo for toxicity in an environmentally isolated test volume, such as an airlock, is one method which could be employed to control this hazard. Figure A-16 shows schematically a possible method for testing which is based on the following assumptions:

1. Vessels containing toxic substances are contained within a larger pressurized container.
2. Vessels containing toxic substances are subject to leakage or breakage.
3. The container is designed to be compatible with the toxicity test; it is fitted with necessary valves, etc.
4. Leakage from plumbing connections during the testing operation is possible, and thereby require an environmentally isolated test volume.

As can be seen from the figure, the container can be vented to space if a toxic atmosphere is detected.

Model	Mission Phase	Pictorial Representation
A	Orbital Maneuvers	
B	Deployment, Checkout, Servicing, Cargo Handling	

				PRESSURIZED PAYLOAD ECLSS		
Config-uration	Ref. Model	Manned Payload	Unmanned Payload	By Orbiter	By Payload	Not Required
1	A	X		X		
2	A	X			X	
3	A		X	X		
4	A		X		X	
5	A		X			X
6	B	X		X		
7	B	X			X	
8	B		X			X

Figure A-15. Configurations Which Can Lead to Toxic Environment in Orbiter



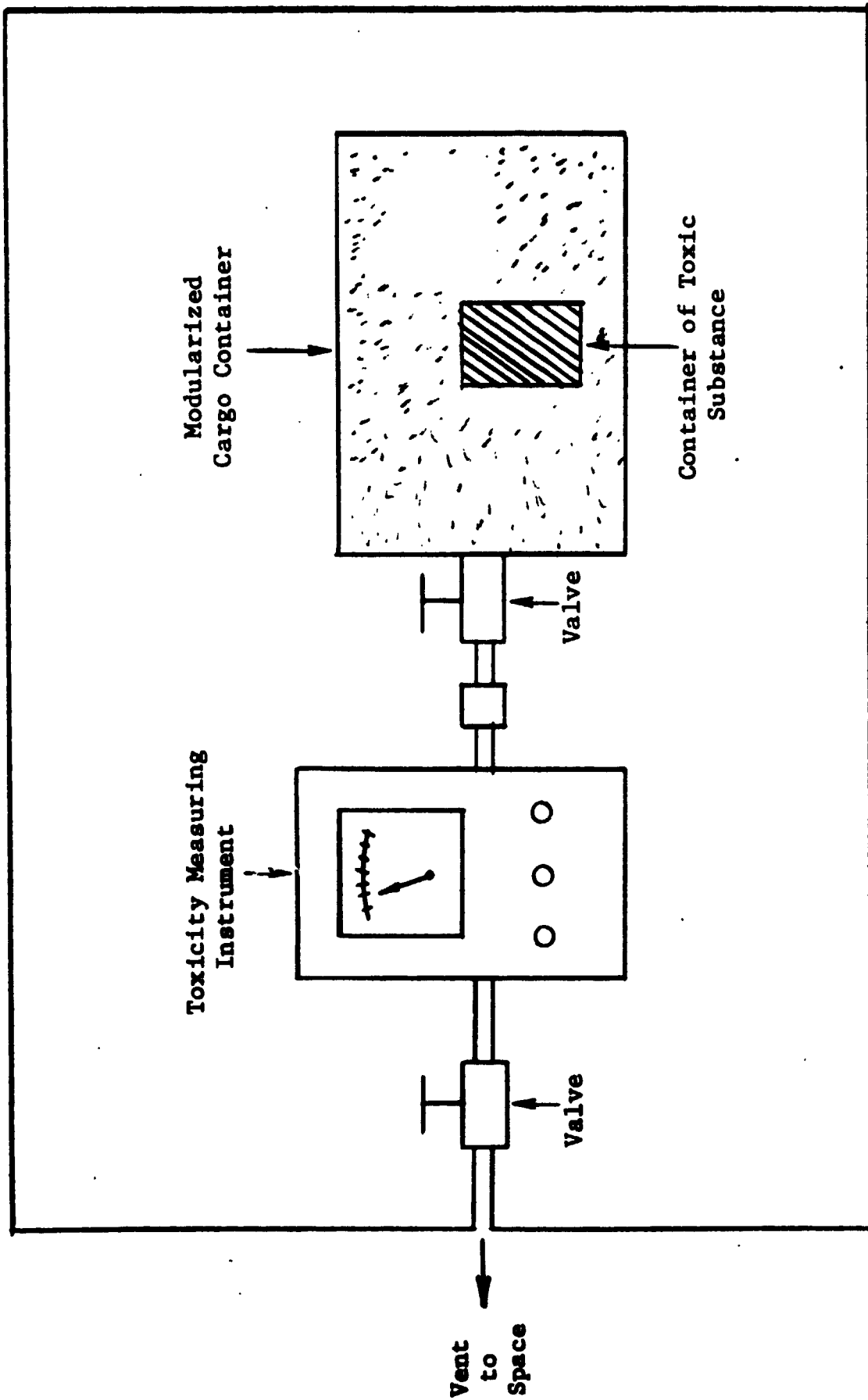


Figure A-16. Airlock for Testing Toxicity of Cargo



### A.13 MAXIMUM SAFE TANK CONTENTS

Gaseous leakage from an upper stage vehicle tank into the orbiter cargo bay cannot be allowed to overpressurize the bay. The resulting damage to the Shuttle structure and cargo bay doors could, in extreme cases, cause loss of the entire vehicle, including the crew, during reentry. For less severe cases, the structure could bend or break, allowing hot atmospheric plasma to enter internal volumes containing critical components.

Limiting the gaseous contents of upper stage vehicle tanks to the value shown for a typical case in Figure A-17 could prevent overpressure from the leakage or rupture of any one tank. Each independent tank would not provide enough gas to increase the cargo bay pressure above the design limit (13,800 N/m<sup>2</sup>, 2 psi, in this case) even under the restriction of no venting. Immediate expansion of gas into the cargo bay is the worst case, since some upper stage vehicle tank leakage over time would also allow some cargo bay outflow. Immediate expansion also restricts the heat transfer, so the process can approach isentropic. The general relationship for isentropic state changes for a perfect gas is:

$$p_2 V_2^\gamma = p_1 V_1^\gamma$$

where  $p$  = gas pressure  
 $V$  = gas volume

Subscript 1 denotes the initial pressure and volume of the gas in the tank, and subscript 2 the expanded values, i.e., the allowable pressure in the cargo bay, and the cargo bay volume (assuming it is all available for expansion).

Figure A-17 shows the allowable relationship between tank pressure and volume. This result takes advantage of the decrease in gas temperature during expansion to allow high initial tank pressures in relatively small tank volumes. The final low temperature reduces the immediate specific volume, so that a larger weight of gas is acceptable to the Shuttle structural strength. It is therefore better, from the point of view of potential cargo bay overpressurization, to transport large quantities of gas in the orbiter cargo bay at high rather than low pressure (assuming the same storage temperature). For example, a typical Space Station module contains 156 m<sup>3</sup> (5500 ft<sup>3</sup>) of air at 10<sup>5</sup> N/m<sup>2</sup> (14.7 psi). This point is on the unsafe side of the curve, i.e., a massive leak from the module could damage the orbiter cargo bay. If the same quantity of air is stored in a tank of 1.56 m<sup>3</sup> (55 ft<sup>3</sup>) at a pressure of 10<sup>7</sup> N/m<sup>2</sup> (1470 psi), and the module is now vented to space during launch and only pressurized after station assembly, a rupture of the tank will not now overpressurize the cargo bay, as shown by the fact that this point now lies on the safe side of the curve.

The final gas state after a leakage continues to change slowly due to heating from the cargo bay structure, but venting will compensate for the specific volume increase. The curve is conservative because no gas condensation to solid was considered, i.e., sublimation pressures are extremely small.

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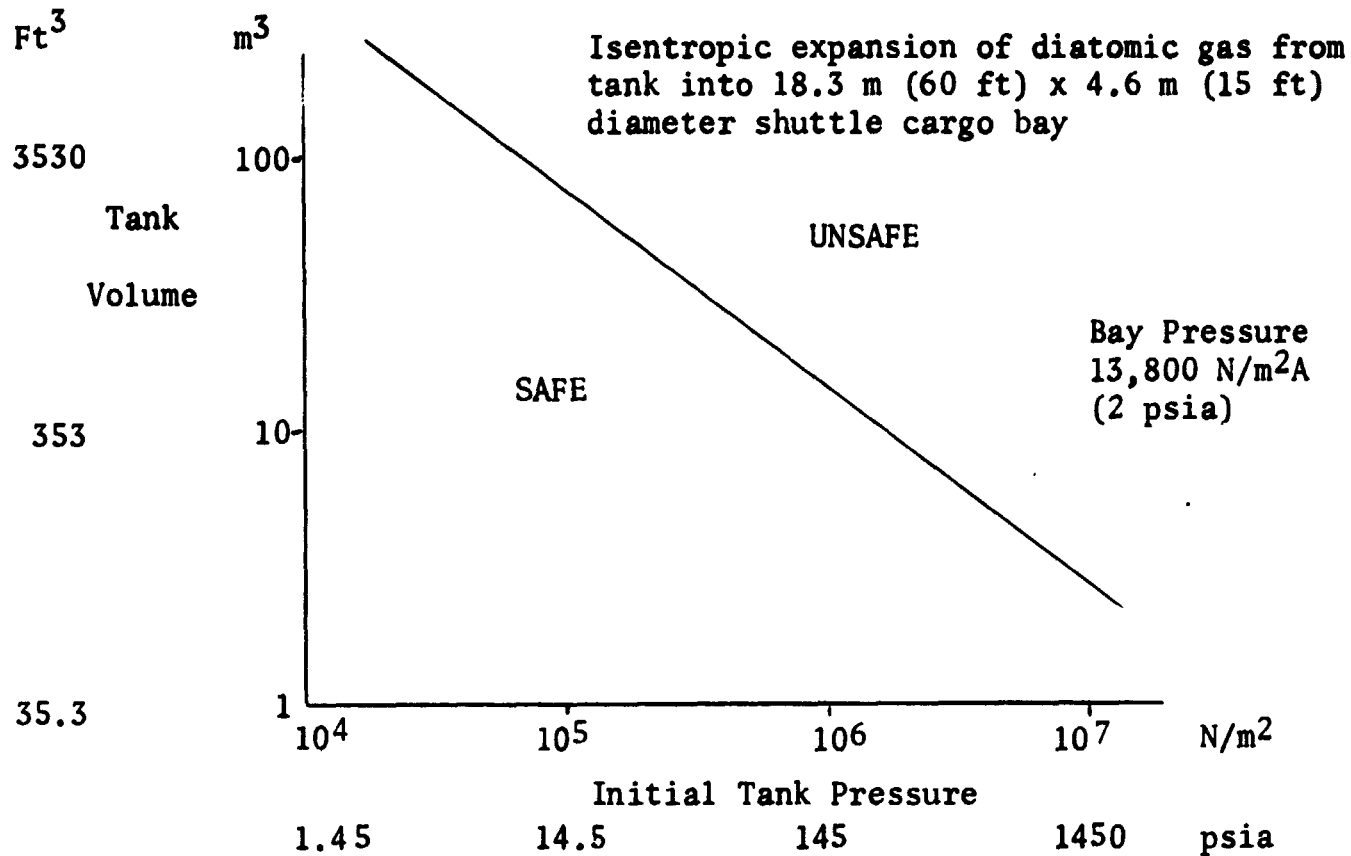


Figure A-17. Safe Content of Gas Tanks

#### A.14 MAXIMUM SAFE TANK CONTENTS - LIQUID

Safe liquid content of upper stage vehicle tanks is a function of the amount of gas generated when liquid leakage occurs. Storable propellants release a small amount of gas because of rapid solidification. The difference between solidification temperature and normal operating temperature is small and the heat lost through evaporation is large, e.g., one pound of water at 21°C (70°F) requires only 0.073 kg (0.16 lb) of water evaporation to freeze. In contrast, cryogenic propellants vaporize a larger percentage of the liquid before the remainder is solid; e.g., at least 25% for hydrogen and 53% for oxygen. Expansion to a higher pressure than vacuum may result in a decrease in the amount of gas generated, but at a higher temperature. Specific analysis is required for each combination of liquid and storage conditions to identify safe liquid tanks volumes.

Some upper stage vehicle tanks may not be within the allowable contents to preclude overpressurization of the cargo bay in the event of leakage. Reduction of pressure and/or volume could be made for improved safety.

Volume reduction to reduce the potential effects of a failure of any one tank could be accomplished by the use of multiple tanks or compartmentation of the larger sizes. Multiple tanks are more feasible for high pressure storage because of the increased efficiency of structural shape possible.



Compartmentation could be used for larger, low pressure volumes, where bulkheads need not have excessive weight. In most cases, however, the tank configuration has already been determined by existing designs (e.g., Centaur, Agena, Apollo service module), or will be determined by other considerations.

Pressure reduction is more flexible because variation with time is possible and in some cases desirable. Merely reducing the pressure by regulator setting is a step in the right direction for liquid propellants because it could result in safe tank contents, and it does reduce the driving force for leakage. Storage of the additional gas for operational pressurization imposes no weight penalty in the gas quantity and only a small weight increase in the high pressure gas tanks.

Further improvement for low leakage can be achieved by cutting off the pressurization supply to the lower pressure tanks entirely prior to upper stage vehicle operation. Leakage will then decrease the internal pressure and temperature still further, with a direct decrease in leakage flow. Should only liquid be exposed to the leak source, all the liquid would normally be expelled. However, if only pressurizing gas were exposed to the leak source, much of the liquid in the tank would be solidified and would not be available for leakage until significant heat transfer had increased the vapor pressure. The time history of the leak would be much more gradual and would give the Shuttle vents the time to dissipate the early leakage. Therefore, the cargo bay pressure rise would be more gradual with a lower peak.

#### A.15 ORBITER CARGO BAY VENTS

Venting of the orbiter cargo bay starts with the launch and re-entry transients. The atmospheric gas flow is out and in, respectively, and the practical solution is always-open vent holes. However, vent sizing for this condition does not consider the possibility of upper stage vehicle leakage at the same time. These holes must be small enough to prevent excessive ingestion of hot, atmospheric plasma; therefore, the individual and total hole area is limited. In addition, payload leak rates during on-orbit operations with the cargo bay doors closed could result in bay overpressure; e.g., leaks from large propellant tanks and large, pressurized modules which are more than one-half the cargo bay in volume.

Increased venting capacity could be available through differential pressure activated relief valves. Single direction venting from inside the cargo bay, to space would be sufficient because the intent is to prevent orbiter disaster as a result of upper stage vehicle large leakage into the bay or generation of large quantities of gas in the bay through fire. Although large leakage and fire are unlikely, they are hazards whose effects involve grave consequences for orbiter crew and equipment. Tradeoff of risk with venting capacity should be made during detailed design of orbiter and payload.

Completely open cargo bay doors essentially provide a space environment. The space exposed side of the orbiter payload has no confinement and could accept all leakage without overpressure; but the orbiter side could still be locally confined as a consequence of cargo bay wall proximity to the upper

stage vehicle. With reasonable precaution in installation design, the likelihood of cargo bay overpressure should be acceptably small. Open cargo bay doors to the maximum extent possible while in earth orbit resolves several particular hazards and is therefore recommended.

The complete orbiter of shuttle cargo bay venting is shown in Figure A-18.

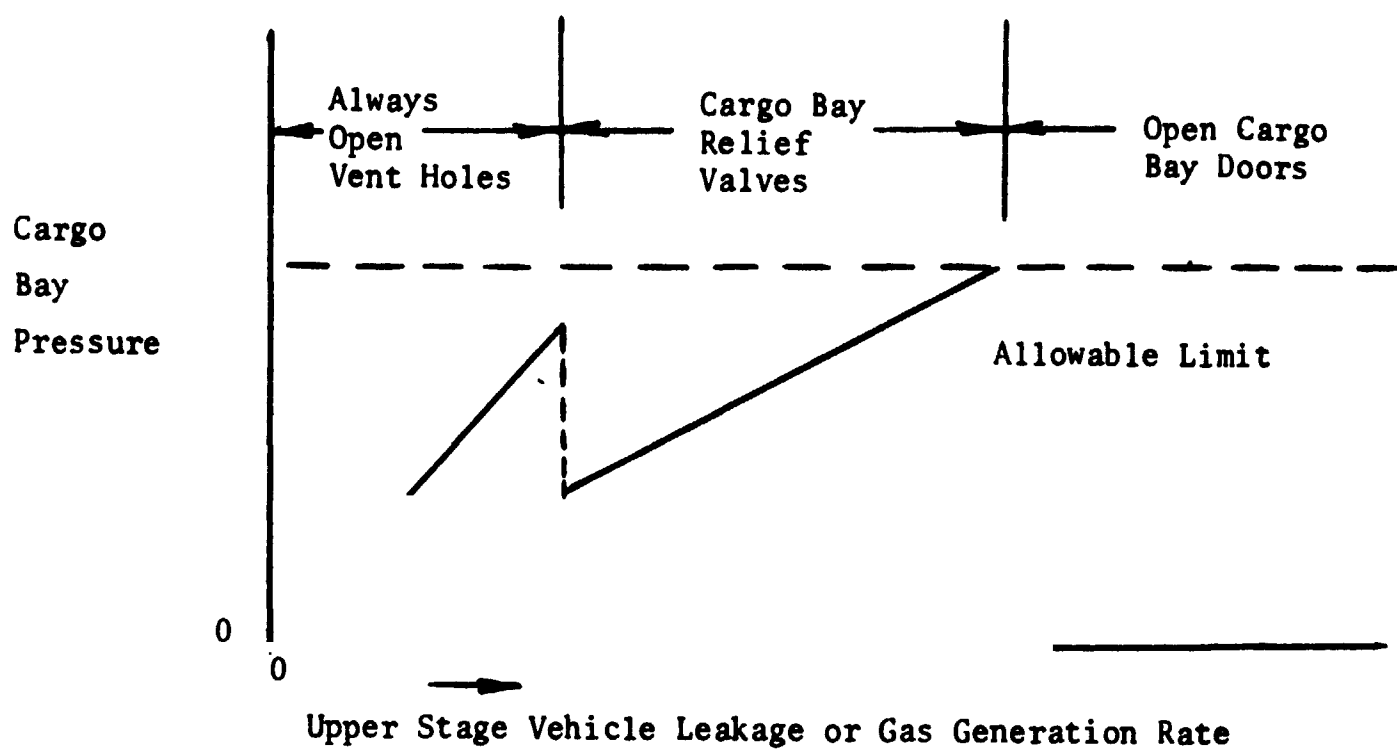


Figure A-18. Cargo Bay Venting Spectrum

Any on-orbit operations that could prevent door closure following payload activities are hazardous to the orbiter. A current orbiter requirement is closed cargo bay doors during reentry due to aerodynamic buffeting and heating. Payload activities in orbit generally require opening of the cargo bay doors to expose sensors to the space environment or to off-load free flying vehicles into space. Possible incorporation of environmental control cooling radiators on the door internal surfaces would also require door opening for on-orbit use. Some upper stage vehicle installation configurations (e.g., Centaur) have recommended vent, electrical, fitting and dumping connections through the door. Any one of these hard connections could interfere with the door closing by misalignment of either mating piece. Retrieved upper stage vehicle indexing within the orbiter would have to be very precise. Connections would be inaccessible to orbiter crew by IVA or EVA because of small clearances. Therefore, connections to the doors are not recommended because of added hazard and low flexibility.



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An alternate location of interconnections between upper stage vehicles and the orbiter would be from the upper surfaces (those exposed to space when the door is open) of the upper stage vehicle to the cargo bay walls. This location would allow connection independent of either upper stage retrieval into the bay, or of the cargo bay door closing. In addition, the connections would be accessible to manned adjustment and repair before de-orbit.

#### A.16 ORBITER CREW CONTROL

The prime safety requirement of the upper stage vehicle/orbiter combination is return of the crew to earth. The only immediate means is the orbiter. Monitoring for performance abnormalities by the crew provides the information necessary upon which to base mission continuation or abort decisions. Computer control can provide some normal operating sequences, but the more complex normal and abort sequences may be performed by crew control more effectively. The crew can provide an interlock capability for hazardous operations without additional weight and with crew assurance.

One of the most severe hazards from upper stage vehicles is overpressure of the tanks with subsequent explosion. Crew monitor of tank pressure is a back-up for the automatic measure, and crew control of vent and pressurizing valves is a back-up for automatic pressure level control; this may include separate sensors and readouts for the orbiter crew, over-ride opening and closing of the vent valves, and over-ride opening and closing of pressurizing gas supply valves. Where inadvertent initiation of upper stage vehicle processes could present a hazard to the orbiter, a separate cut-off should be available to the orbiter crew; e.g., electricity to the upper stage vehicle engine start valves. Switchover from orbiter crew command control to upper stage vehicle internal control should occur only when the orbiter is either out of hazard range entirely or is capable of performing evasive maneuvers to avoid a failed upper stage vehicle under the case of maximum possible vehicle acceleration.

#### A.17 ORBITER CARGO BAY ISOLATION

Several orbiter hazards from upper stage vehicles or any one of a variety of payloads could propagate into orbiter equipment through proximity; e.g., overpressure from leakage, pressure shock from explosion, shrapnel impingement from explosion, and excessive heat transfer from fire. In case of emergencies resulting from such hazards, remedial action must be taken by the orbiter crew in order to return safely to the ground.

The orbiter equipment necessary for de-orbit, reentry, and landing must remain in a safe operating mode, but orbiter equipment surrounding the cargo bay has a higher chance of being damaged than remote equipment. Much equipment must be placed in and near the cargo bay because of functional requirements and in order to minimize the orbiter total volume. Orbiter equipment required for safe return should not be placed in exposed positions around the cargo bay because of the added risk. In addition, damage to this nearby equipment can be prevented from affecting remote equipment by the expedient



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of isolation. Isolation can be implemented by interlocks or shutoff valves within branches of the subsystem, or by separate subsystems which interface through isolating components; e.g., cathode followers, heat exchangers, and information storage.

Isolation of the external interface between orbiter and upper stage vehicle requires consideration of fragment barriers and thermal insulation. These safety devices could be placed on each payload according to the peculiar requirements or on the orbiter as a minimum common requirement that does not penalize upper stage performance; e.g., a single insulation on the orbiter cargo bay surface (inner or outer) which ameliorates all three effects.

The orbiter cargo venting system should be isolated from the rest of the orbiter venting system. Interstices between the orbiter tanks and conduits need to be vented to the atmosphere and space during ascent and re-entry. Combining the vent system for the two volumes would increase the number of failure modes applicable to the orbiter tanks; e.g., corrosion from upper stage vehicle, corrosive fluid leakage and increased heat transfer into orbiter cryogenic propellants (for orbiters with internal hydrogen and/or oxygen tanks). Leakage from any upper stage vehicle would destroy the hard vacuum surrounding orbiter cryogenic tanks which is necessary for insulation effectiveness. In addition, any leak in the orbiter tanks would increase the pressure experienced by the orbiter cargo bay. Providing a separate venting system for each volume would confine failures to the locality of the initial failures, and would improve the possibility of remedial action.

In summary, the orbiter cargo bay venting system should normally be separate from the orbiter tank volume venting system. Always-open vent holes to space could be used for both. Vent requirements could be satisfied by relief valves between the two volumes (simultaneous emergencies in both volumes are unlikely) or between each volume and space. The more likely small leaks should be well within the always-open vent capacities determined by launch and re-entry requirements. Requirements of open shuttle cargo bay doors and avoidance of internal confined volumes would provide the maximum venting over the longest time period. The current orbiter time-line includes short periods of operation in orbit with the cargo bay doors closed immediately on achieving orbit and again before de-orbit.

#### A-18 ROCKET ENGINE INSTABILITY

Rocket engines utilize very high temperature gases in the violent chemical reaction of combustion to provide efficient thrust in space. Control of this process is primarily empirical in current designs. Extensive testing is required to explore the stable region of the particular design used and safeguards are provided for insuring operation only within that region, but uncontrolled combustion is still possible. The effects of uncontrolled combustion are catastrophic to the engine and immediate surroundings through flame, shrapnel, loss of full thrust, and misdirected thrust.



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Checkout of attitude control engines before upper stage vehicle release, if required, should occur in the fully extended position, if possible. Attitude hold immediately following release should be performed by cold gas jets or by engines on the opposite side of the upper stage vehicle from the orbiter.

Intentional operation of upper stage vehicle main rocket engines should be planned only when remote from the orbiter, and main engine burn should be initiated at a distance from which evasive action by the orbiter could prevent damage or collision. Return of an upper stage vehicle to the orbiter can be performed in a similar manner; e.g., turn off upper stage vehicle main engine before orbiter approach and switch to cold gas jets when near the orbiter.

#### A.19 HAZARDOUS FLUIDS IN 1971 BLUE BOOK EXPERIMENTS

An analysis was made of the 1971 Blue Book to identify fluids which are specified in the various experiments. Tables A-12 through A-18 present the 1971 Blue Book experiments, by discipline, with the associated fluids where specified. Quantities, pressures, volumes and other relevant parameters are shown where available.



Table A-12. 1931 Blue Book - Volume II (Astronomy)



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Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1. X-RAY STELLAR ASTRONOMY				Unspecified
1.4.1 High Resolution X-Ray Telescope Experiments	Coolant			
1.4.2 Large Area Moderate-Resolution X-Ray Telescope Experiments	--			
1.4.3 Proportion Counter Array Experiments	--			
1.4.4 Scintillation Counting	--			
1.4.5 Crystal Spectrometer Experiment	--			
1.4.6 Transient X-Ray Phenomena Detection Experiment	--			
2. ADVANCED STELLAR ASTRONOMY				
2.4.1 Technology Experiments	--			
2.4.2 Stellar Observation Experiments	--			

Table A-12. 1971 Blue Book - Volume II (Astronomy) (Cont)



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Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
3. ADVANCED SOLAR ASTRONOMY				
3.4.1 Photoheliograph Experiments	--			Safety Analysis indicates some hazard in the use of some materials used in imaging tubes which may be poisonous if accidentally broken.
3.4.2 XUV Spectroheliograph Experiments	--			
3.4.3 X-Ray Grazing Incidence Telescope Experiments	--			
3.4.4 Solar Coronagraph Experiments	--			
4. INTERMEDIATE SIZE UV TELESCOPES				
4.4.1 Narrow-Field UV Telescope Experiments	--			
4.4.2 Wide Field UV Telescope Survey Experiments	--			
5. HIGH ENERGY STELLAR ASTRONOMY				
5.4.1 Low Energy X-Ray Telescope Experiments (0.1 to 5 KeV)	Gas	210 lb		Gas supplies indicated for Venetian Blind X-Ray Assembly

Table A-12. 1971 Blue Book - Volume II (Astronomy) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
5.4.2 X-Ray Source Mapping	--			
5.4.3 Narrow Band Spectrometer and Polarimetry (6 to 10 KeV)	--			
5.4.4 Large Area X-Ray Counter Measurements (0.1 to 100 KeV)	--			
5.4.5 Cosmic X-Ray Energy Spectra (6 to 400 KeV)	--			
5.4.6 Gamma Ray Spectrometry	--			
5.4.7 High Energy Gamma Ray Measurements with a Large Area Spark Chamber	--			
6. INFRARED ASTRONOMY				
6.4.1 Detector Array Scanning	LNe	600 lb	8 ft <sup>3</sup> in 2 Tanks	Stored in two super-insulated 3.5' x 3.5' x 8' Dewar tanks. LNe temp $\approx$ 27.6 K

Table A-12. 1971 Blue Book - Volume II (Astronomy) (Cont.)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
6.4.1 Detector Array Scanning (continued)	LHe	500 lb	54 ft <sup>3</sup>	Stored in 3.5' x 3.5' x 8' tanks. LHe temp ≈ 2.2 K
6.4.2 Radiometry	--			
6.4.3 High Resolution Spectrometry	--			



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Table A-13. 1971 Blue Book - Volume III (Physics)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1. SPACE PHYSICS RESEARCH LAB				
1.4.1 Atmospheric and Magnetospheric Science (Including Aurora)	N <sub>2</sub>			
1.4.2 Cometary Physics-- Gaseous Release of NH <sub>3</sub> and ICN <sup>16</sup>	NH <sub>3</sub> (ammonia), ICN <sup>16</sup> (Iodide cyanide), NH <sub>2</sub> , CN, N <sub>2</sub> H <sub>4</sub> (hydrazine), NH, OH			ICN exists as solid at room temperature. Substances indicated are released during experi- ments.
1.4.3 Meteoroid Science	--			
1.4.4 Small Astronomy Telescope	--			
2. PLASMA PHYSICS AND ENVIRONMENTAL PERTUBATION LAB				
2.4.1 Investigation of the Plasma Wake Around Orbital Bodies	Hydrazine			Potential use to power Hydrazine Turbo Alternator
2.4.2 Investigation of Plasma Resonances and their Harmonics	--			



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Table A-13. 1971 Blue Book - Volume III (Physics)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
2.4.3 Investigation of Wave-Particle Interactions with VLF	--			Experiment nuclear species or groups are indicated.
2.4.4 Investigation of Electron and Ion Beam Propagation	--			
3. COSMIC RAY PHYSICS LAB				
3.4.1 Charge and Energy Spectra of Cosmic Ray Nuclei	Protons, Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Fluorine, Iron			
3.4.2 Electron and Positron Energy Spectra and Anisotropes	--			
3.4.3 Isotopic Composition of Light Elements	--			
3.4.4 Search for Nucleonic Antimatter	--			
3.4.5 Extremely Heavy Nuclei	Nuclear Emulsion	66 lb		

Table A-13. 1971 Blue Book - Volume III (Physics)



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Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
4. PHYSICS AND CHEMISTRY LAB				
4.4.1 Molecular Beam Scattering	$O_2$ , $O$ , $He$ , $N_2^+$ , $O_2^+$ , $O^+$ , $e^-$	50 lb Total		Gas supply for experiments
4.4.2 Gas Surface Interactions	Be, C, Al, Fe, Ni, Cu, Ag, Pb, Au, SiO, SiO <sub>2</sub> , BaF <sub>2</sub> , ZrO <sub>2</sub> , O, N <sub>2</sub> , O <sub>2</sub>			Light and Heavy Atomic Weight Materials Coating Materials
4.4.3 Flame Chemistry and Reaction Kinetics at Zero-G	Hydrocarbons Helium Carbon Tetrafluoride Paraffin Hydrocarbon Magnesium Aluminum Sulphur	300 lb Total		
4.4.4 Chemical Lasers	Polycarbonate Fuel Rods Oxygen CO, O, CO <sub>2</sub>	100 lb 200 lb		
4.4.5 Quantum Effects at Low Temp and Zero-G	Liquid Helium Superfluid Helium Helium Mercury Aluminum Powder			Superfluid Helium will not boil.

Table A-13. 1971 Blue Book - Volume III (Physics)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
4.4.6 Gas Reactions in Space	LiF  NO, Acetylene  Trimethylaluminum, Diborane, BaO			Window material of storage vessels,  Cases in cannisters  Compounds
4.4.7 Heat Transfer in a Convectionless Medium	N <sub>2</sub> Freon	15 lb 100 lb		
4.4.8 Critical Point Phenomena	Xenon SF <sub>6</sub> (Sulfur Hexoflouride) CO <sub>2</sub>			



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Table A-14. 1971 Blue Book - Volume IV  
(Earth Observations)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1. EARTH OBSERVATIONS	Nitrogen and Argon Cryogen			Liquid or solid cryogen for sensor cooling. 437 lb of consumables including magnetic tape, film and cryogenics.
1.4.1 Area I, Meteorology & the Atmospheric Sciences	--			
1.4.2 Area II, Land Use Mapping	--			
1.4.3 Area III, Air & Water Pollution	--			
1.4.4 Area IV, Resource Recognition and Identification	--			
1.4.5 Area V, Natural Disaster Assessment	--			
1.4.6 Area VI, Ocean Resources	--			
1.4.7 Area VII, Special Research	--			



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Table A-15. 1971 Blue Book - Volume V

(Communications/Navigation)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1. COMMUNICATIONS/ NAVIGATION				
1.4.1 Optical Communications and Propagation	--			
1.4.2 MM Wave Communications and Propagation	--			
1.4.3 Surveillance, Search and Rescue	--			
1.4.4 Satellite Navigation Techniques for Terrestrial Users	--			
1.4.5 On Board Laser Ranging	--			
1.4.6 Autonomous Navigation System for Space	--			
1.4.7 Transmitter Breakdown Tests	--			
1.4.8 Terrestrial Noise Measurements	--			



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Table A-15. 1971 Blue Book - Volume V  
(Communications/Navigation) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1.4.9 Noise Source Identification	--			
1.4.10 Susceptibility of Terrestrial Systems to Satellite Radiated Energy	--			
1.4.11 Tropospheric Propagation Measurements	--			
1.4.12 Plasma Propagation Measurements	--			
1.4.13 Multipath Measurements	--			

Table A-16. 1971 Blue Book - Volume VI

(Materials Science and Manufacturing)



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Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1.4.1 Metallurgical Processes	Phenol, Formaldehyde, Liquid Metals, Oxygen, Dielectrics (Oxides), Silicate Salts, Refractory Materials such as Carbides, Borides, and Binary Hafnium Compounds			3475 K maximum temp, Isotope storage provided, S-08 Accident Control System provided
1.4.1.1 Composite Materials	Potassium Sodium Niobate, Potassium Sodium Silicate Solvent, $\text{NH}_4\text{Al}_2(\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}$ , $\text{Ni}(\text{SO}_4)$ , Gallium Arsenide, Liquid Gallium, Fused Silicate Solution			Gallium Arsenide, Liquid Gallium to be used in SKYLAB I.
1.4.1.2 Metal Foams and Controlled				
1.4.1.3 Density Materials				
1.4.1.4 Free Casting				
1.4.1.5 Liquid Dispersions				
1.4.2 Crystal Growth				
1.4.2.1 Crystal Growth from Solution				
1.4.2.2 Single Crystal Growth from Melts				
1.4.2.3 Crystal Growth from Vapor				
1.4.2.4 Supercooling and Homogeneous Nucleation				
1.4.3 Glass Process	Mixtures of Oxides such as $\text{Al}_2\text{O}_3$ , $\text{ZrO}_2$ , $\text{HfO}_2$ , $\text{TiO}_2$			Solids
1.4.3.1 Preparation of Glasses				
1.4.3.2 Glass Processing				

Table A-16. 1971 Blue Book - Volume VI  
(Materials Science and Manufacturing) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1.4.4 Biological Processing	Pathogenic and Highly Toxic Materials			Samples supplied in Aqueous solution
1.4.4.1 Electrophoretic Separation				
1.4.4.2 Lyophilization (freeze drying)				
1.4.5 Physical Properties of Fluids	Unspecified Fluids			
1.4.5.1 Convection				

Table A-17. 1971 Blue Book - Volume VII (T - Technology)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1. CONTAMINATION MEASUREMENTS	--			Resupply - None
1.4.1 Sky Background Brightness Measurement	--			
1.4.2 Real Time Contamination Measurement	--			
1.4.3 Surface Degradation Experiment	--			
1.4.4 Contaminant Cloud Composition Measurement	--			
1.4.5 Contaminant Dispersal Measurement	--			
1.4.6 Integrated Real-Time Contamination Monitor: Optical Module Eval.	--			
1.4.7 Active Cleaning Technique Eval.	--			
1.4.8 Contamination Control Evaluation	Unspecified			Provides gas cushion close to critical surface



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Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
2. FLUID MANAGEMENT				Fluids which will primarily support Life Support, Space Propulsion and other fluid systems
2.4.1 Liquid/Vapor Interface Stability	Freon 11 Hexane, Methanol, Pentane, Freon	450 lb		Resupply - None
2.4.2 Boiling Heat Transfer	LH <sub>2</sub>	170 lb		Resupply - None
2.4.3 Capillary Studies	Methanol Ethanol Pentane Helium	560 lb 190 lb 900 lb ?		Resupply - Required only if small fluid tanks are used
2.4.4 Condensing Heat Transfer	Freon 114B2 CN <sub>2</sub> , LN <sub>2</sub> Freon 21	5 lb		Resupply - None
2.4.5 Two Phase Flow Regimes	Pentane Hexane	360 lb		Resupply - None
2.4.6 Propellant Transfer	LH <sub>2</sub> GHe	850 lb 20 lb		Resupply - 550 lb LH <sub>2</sub>



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Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
2.4.7 Long Term Cryogenic Storage	LH <sub>2</sub>	2500 lb	45 psia	Requires 8' dia x 16' L Cryo tank Resupply - 3500 lb LH <sub>2</sub>
2.4.8 Slush Propellants	Slush Hydrogen GHe	175 lb		Requires one full 3' dia x 6' L super-insulated tank Resupply - None
2.4.9 Two Phase Dynamics	Glycol			Resupply - None
2.4.10 Channel Flow Systems	Glycol			Resupply - None
2.4.11 Conical Flow Systems	Glycol			Resupply - None
3. EXTRAVEHICULAR ACTIVITY				
3.4.1 Astronaut Maneuvering Unit	Oxygen	18 lb ea tank	6000 psia	Used in Astronaut Maneuvering Unit for LSS/Propulsion gas. Two 13 inch O.D. tanks required.



Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
3.4.2 Maneuvering Work Platform	*Hydrazine Oxygen (Normal) Oxygen (Emergency) LiOH	210 lb 5 lb 5 lb 10 lb		*Propellant Subsystems Requirements
4. ADVANCED SPACECRAFT SYSTEMS TEST	*Hydrazine Oxygen (Normal) Oxygen (Emergency) LiOH	1100 lb 150 lb 6 lb 7 lb	(12 ft <sup>3</sup> ) (3 ft <sup>3</sup> ) (0.2 ft <sup>3</sup> ) (7 ft <sup>3</sup> )	*Propellant Experiment Requirements
4.4.1 Oxygen Recovery and Blowdown Resistojet	Air CO <sub>2</sub> H <sub>2</sub> O H <sub>2</sub> O <sub>2</sub> CH <sub>4</sub> --			Basic gases generated in experiment
4.4.2 Maintainable Flight Electronics Package Experiment				



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Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
4.4.3 Thermal Coating Refurbishment in Space	(a) IITRI ZNO Silicone (S-13) (b) IITR ZNO Silicate (Z-9) (c) LMSC Thermatrol TiO2 Silicone (6A-100) (d) Schieldahl GT-1015			
4.4.4 Absorption Refriger- ation Cycle Experiment	--			
4.4.5 Leak Detection and Repair	--			
4.4.6 Maintainable Attitude Control Propulsion System	Helium Propellant (unspecified)	165 lb/ month		
4.4.7 Ball Bearing Lubrication	Fluid and Solid Lubricants			
4.4.8 Advanced Guidance Subsystems Evaluation	Cryogenic (unspecified)			Used in cryogenic electrostatic gyroscope

Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres / Vol	
4.4.9 Space Calibration of Solar Cell Standards	--			
4.4.10 Space Exposure Effects on Material Bulk Properties	Material Samples such as thermal control coatings, plastics, composites, adhesives, insulating materials, metals, lubricants, elastomers, seals, sealant, potting materials, etc.			
4.4.11 Space Exposure Effects on Material Fatigue Properties	--			
4.4.12 Fire Sensing and Suppression	Combustibles, including propane Suppression agents such as foams, gels, inert gases	15 lb		~5 lb propane Tests performed in test cell/airlock

Table A-17. 1971 Blue Book - Volume VII (T - Technology) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
5. TELEOPERATION				
5.4.1 Initial Flight Experiment	Nitrogen	80 lb	3000 psi	Cold gas propellant, 10 ft <sup>3</sup> tank, to provide 6000 lb-sec impulse
5.4.2 Functional Manipulation Experiment	Nitrogen	135 lb	3000 psi	Propellant to provide 8250 lb-sec impulse
5.4.3 Ground Control Experiment	--			



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Table A-18. 1971 Blue Book - Volume VIII (Life Sciences)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
PART A. GOALS AND OBJECTIVES				Noxious or poisonous reagents should be expected
PART B. PHYSICAL DESCRIPTION OF CORE AND NON-CORE MULTIPURPOSE UNITS				
B.1 LIFE SCIENCES COMMON OPERATIONS RESEARCH EQUIPMENT (CORE)	N <sub>2</sub> Heat Transport Fluid  pO <sub>2</sub> , pCO <sub>2</sub> , pNH <sub>3</sub> , pH <sub>2</sub> O, pH <sub>2</sub> , p (ethylene) Approximately 40 types of measurements indicated which include electrolytes, LOH and LDH Isoenzymes, Uric Acid Nitrogen, minerals, electrolytes H <sub>2</sub> , He, air, or O <sub>2</sub>  Standardization Solutions	-- 1600 lb/hr	140 psig 14.5 psid	Pressurant & Purge Gas Type & Temperatures same as Space Vehicle Supply  Atmos gas monitoring measurements   Balance Studies  Required for gas chromatograph  Required for pH meter

Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
B.2 SPECIMENT RETURN UNIT	--			Gamma Isotope Radiation Source  Reference figure 6 D021 Hardware, page 47
B.3 BIOLOGICAL RESEARCH CENTRIFUGE	--			
B.4 RADIOBIOLOGY UNIT	Co <sup>60</sup> or Cs <sup>137</sup>	2-3 curies		
B.5 AIRLOCK/EVA CAPABILITY UNIT	Airlock Pressurization Gases			
1. MEDICAL RESEARCH FACILITY				
1.4.1 Neurological Function	--			
1.4.2 Cardiovascular Function	--			
1.4.3 Renal Function	--			
1.4.4 Nutrition and Metabolic Function	--			
1.4.5 Musculoskeletal Function	--			
1.4.6 Pulmonary Function	--			



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Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)



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Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
1.4.7 Hematologic Function	--			Dissect and freeze specimens
1.4.8 Microbiology and Immunologic Function	--			
1.4.9 Endocrine Function	--			
1.4.10 Clinical/ Therapeutic Function	--			
1.4.11 Environmental Factors	--			
2. VERTEBRATE RESEARCH FACILITY	Dry Ice or LN <sub>2</sub>			
2.4.1 Role of Gravity in Vital Functions	O <sub>2</sub>			
2.4.2 The Role of Gravity in Vertebrate Life Processes	--			
2.4.3 Effect of the Space Environment on Performance and Behavior	--			

Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
3. PLANT RESEARCH FACILITY				
3.4.1 Role of Gravity in Plant Life Cycles and Processes	LN <sub>2</sub> H <sub>2</sub> O C-14 Methionine			C <sup>14</sup> Radioactive Carbon
3.4.2 Graviception and Tropism	--			
4. CELLS AND TISSUES RESEARCH FACILITY				
4.4.1 Role of Gravity in Life Processes of Microscopic Organisms and Cultured Tissues	Nitrite, Nitrate, Sulfide, Sulfate, Phosphate Methane, Carbon Dioxide and Nitrogen			Soil chemical measurements
4.4.2 Effect of the Space Environment in Genetic Subcellular, and Molecular Phenomena	--			
4.4.3 Role of Gravity in Interspecies Relationships	Argobacterium Tumerfaciens			Used for inoculation of carrot disks



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Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres / Vol	
5. INVERTEBRATE RESEARCH FACILITY				
5.4.1 Role of Gravity in Invertebrate Life Processes	CO <sub>2</sub>			
5.4.2 Effect of the Space Environment on Invertebrate Behavior	O <sub>2</sub> , LiF, Si Sr <sup>89</sup>	10 milli-curies		LiF Fluorescent Dosimeter Si Detectors Radiation source for Tribolium experiments
5.4.3 Effect of				
5.4.3 Effect of the Space Environment on Invertebrate Genetics	CO <sub>2</sub> , H <sub>2</sub> S, C <sub>2</sub> H <sub>4</sub> , Hydroquinones			
6. LIFE SUPPORT AND PROTECTIVE SYSTEMS				
6.4.1 Water Recover Methods and Components	GN <sub>2</sub>	5 lb/ 30 days	14-150 psig	Purge and Pressurant Gas
	GO <sub>2</sub>		14-140 psig	
	GH <sub>2</sub>			



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Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
6.4.2 Waste Management Methods and Components	GN <sub>2</sub>	4 lb/ 30 days	14-150 psig	Purge and Pressurant Gas
6.4.3 Advanced Cooling System Methods and Components	--			
6.4.4 Zero Gravity Whole Body Shower	H <sub>2</sub> O			
6.4.5 Advanced Two-Gas Atmosphere Supply and Control System				
6.4.6 Atmosphere Supply Methods and Components	*N <sub>2</sub> , *O <sub>2</sub> , Superoxides, Chlorate Candles, Hydrogen peroxide, Nitrogen Producing Chemicals			*Supercritical, Gaseous Subcritical States
6.4.7 Oxygen Regeneration Methods and Components	H <sub>2</sub> O, KOH, O <sub>2</sub> , CO <sub>2</sub>			Potassium Hydroxide (KOH) is a solid
6.4.8 Carbon Dioxide Collection Methods and Components	--			



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Table A-18. 1971 Blue Book - Volume VIII (Life Sciences) (Cont)

Experiment	Item	Container		Comments
		Qty	Pres/ Vol	
6.4.9 Advance Trace-Contaminant Control and Monitoring Sub-System	--			
6.4.10 Protective Clothing and Advanced Space Suit Assemblies	--			
6.4.11 EVA Suit and Biopack	--			
6.4.12 Food Storage, Preparation, and Feeding Methods	--			
7. MAN-SYSTEM INTEGRATION				
7.4.1 Behavioral Effects	--			
7.4.2 Performance Capability Assessment	--			
7.4.3 Habitability and Proficiency Maintenance	--			
7.4.4 Behavioral Effects and Performance in Rotogravitation	--			



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## A.20 RADIOACTIVE EXPERIMENT SOURCES

The radioactive sources identified from a review of the 1971 NASA Experiments Blue Book are listed in Table A-19.

Table A-19. Identified Radioactive Sources

Source	Quantity	Discipline	Experiment	Usage
Co <sup>60</sup> or Cs <sup>137</sup>	2-3 curies	Life Sciences	Radiobiology	Gamma Isotope Radiation Source.
C-14 Methionine	Unknown	Life Sciences	Role of gravity in life processes of microscopic organisms and cultured tissues.	---
Sr <sup>89</sup>	10 milli-curies	Life Sciences	Effect of the space environment on invertebrate behavior.	Radiation Source for tribolium experiments.

As can be seen from the above table, cobalt-60 and cesium-137 Gamma Isotope Radiation Sources could present a significant radiation hazard if shielding is damaged while in the orbiter cargo bay or during cargo handling and transfer operations. Typical characteristics of 1 curie of these isotopes as shown below:

Isotope	Half-Life	Roentgens Per Hour at 1 Ft	Roentgens Per Hour at 1 Meter
Co <sup>60</sup>	5.3 yr	14.3	1.3
Cs <sup>137</sup>	30 yr	3.4	0.32

A radiation hazard due to spillage is not anticipated for Co<sup>60</sup>, since it would be expected to be a solid metallic material and not subject to rupture; however, radioactive sources which are of a powdered form enclosed in capsules could present a spillage hazard.

Shielding requirements for limiting design dose rates to 0.1 R/week in working areas are shown in Figure A-19 and illustrate typical industrial design standards for Co<sup>60</sup> and Cs<sup>137</sup>.

## A.21 MINIATURE AIRLOCK FOR PLUMBING INTERFACE CONNECTIONS

A potential hazard during transfer of hazardous fluids between containers in mated modules via piping, is the possibility of fluid leakage from plumbing interface connections into habitable vehicle volumes. Safety considerations for the non-mated module make it desirable that terminal points of transfer



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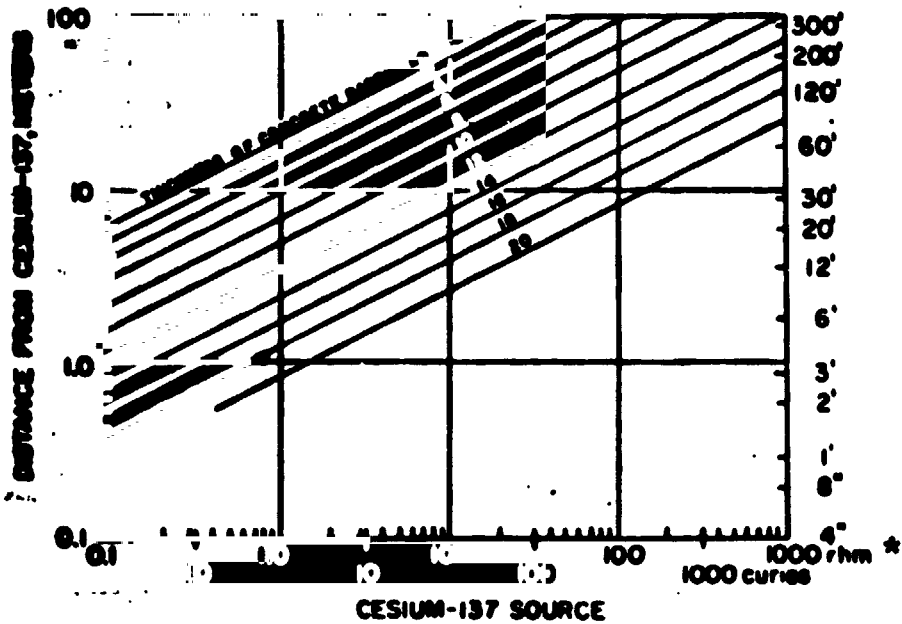
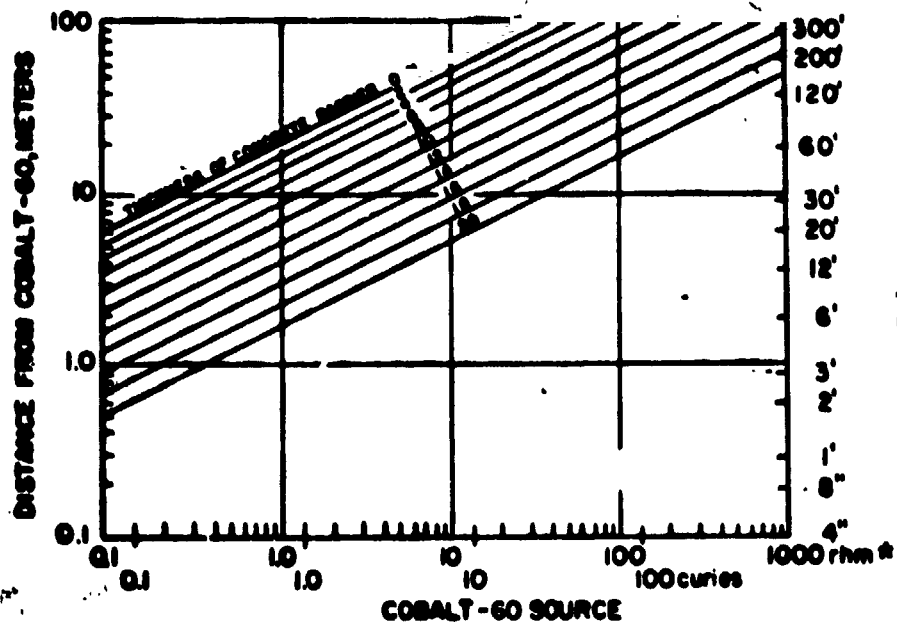


Figure A-19. Radioactivity of Cobalt 60 and Cesium 137



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lines for hazardous fluid containers be vented to space. However, after mating it is desirable to make module plumbing interface connections in a shirtsleeve environment, but perform subsequent transfer operations with the plumbing interface connections vented to space. A possible way to accomplish these objectives is through use of a miniature airlock which is described, including operations, in Figure A-20.

#### A.22 BOMB BLANKET

A cursory investigation was conducted to determine the feasibility of employing bomb blankets, similar to bomb blankets used by police department bomb squads, to contain explosions of pressure vessels and pyrotechnic devices. Contact with the Los Angeles Police Department Bomb Squad provided the following information on the commercially available blankets.

##### Blanket Manufacturer:

Davis Bomb Blanket Corporation  
Scutters and Woodbone Ave.  
North Port, Long Island 11768

##### Blanket Characteristics:

Size:	1.2m x 1.2m x 0.6cm (4 ft x 4 ft x 1/4 in)
Weight:	11 kg (25 lb)
Material:	Laminated Ballistic Material
Test Devices:	MK2 hand grenade and various pipe bombs ranging in size from 1.3cm (1/2 in) to 3.8cm (1 1/2 in) internal diameter x up to 20cm (8 in) length filled with various types of gunpowder.
Test Results:	Limited shock wave reduction with approximately 90% shrapnel containment.

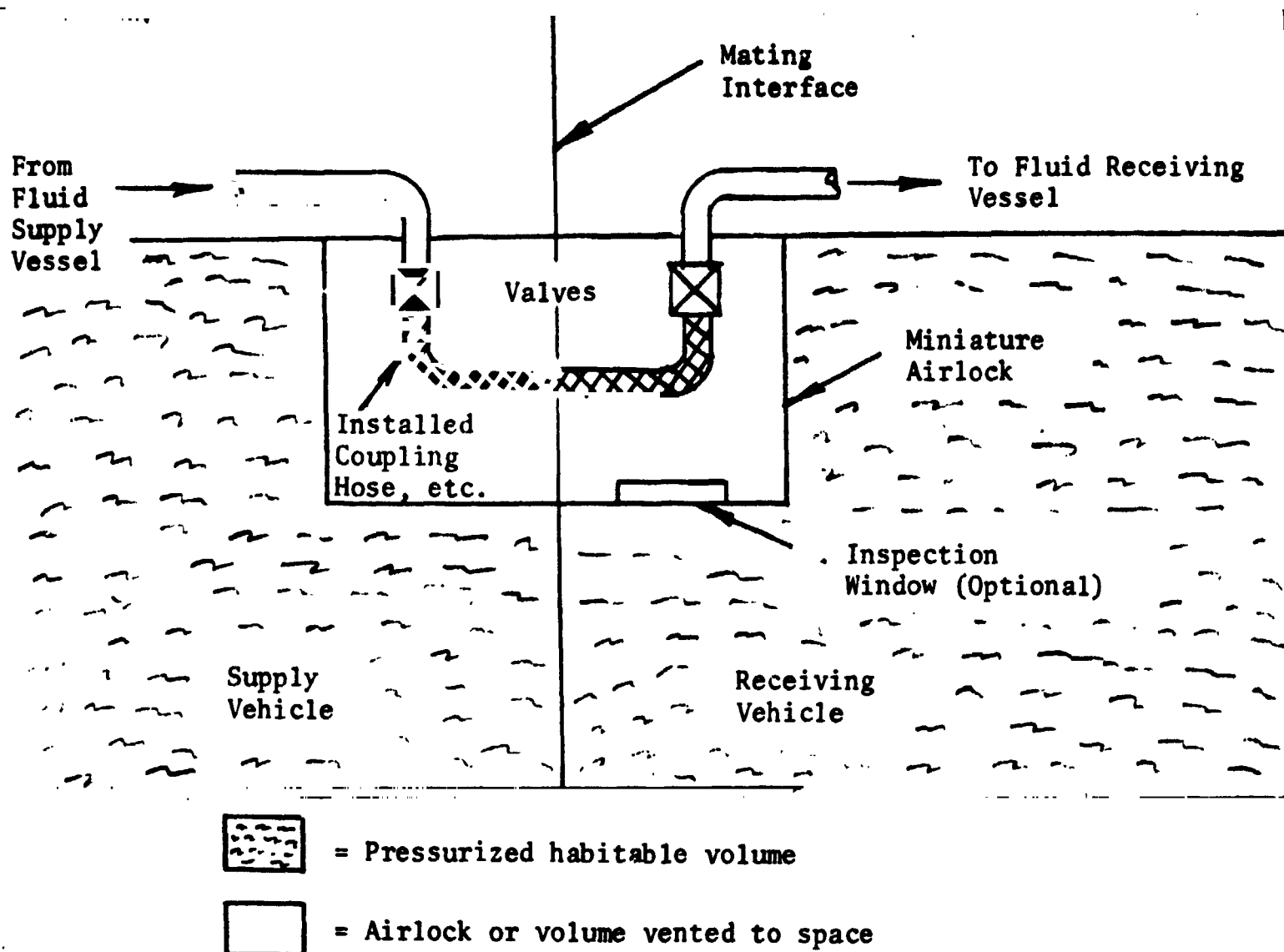
The use of such blankets does not appear feasible for protecting large pressure vessels because of the large weight penalties involved and the ability to prevent shrapnel from small TNT equivalents only. Technology advances in blanket material and design could possibly improve the controllable energy levels to values of the order of pounds of TNT equivalent. An additional disadvantage is that total shrapnel containment is not accomplished.

It appears feasible however, that the blankets, with modification to improve shrapnel containment, could be used to (1) contain explosions and shrapnel of pressure vessels with energy levels on the order of 0.01 kg (0.022 lb) TNT equivalent, (2) provide portable temporary blast shields for personnel performing non-routing maintenance in potentially hazardous volumes, (3) provide portable temporary blast shield for personnel performing repair or disarmament of misfired pyrotechnic devices, or other potentially explosive elements, and (4) provide a blast shield between adjacent pressure vessels.

It is of interest to note that any development effort in this area would have direct applicability to civilian police departments.



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**Operations:**

- Perform mating of supply vehicle to receiving vehicle
- Perform plumbing interface connections in pressurized habitable environment
- Vent airlock to space
- Perform and monitor fluid transfer operations
- Vent plumbing to space or purge with inert gas to clear lines of any residual toxic fluid
- Pressurize airlock
- Remove plumbing interface connections

**Figure A-20. Miniature Airlock for Plumbing Interface Connections**



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#### A.23 MAN-COMPATIBILITY OF TUG WHILE IN OR NEAR ORBITER

Upper stage vehicles must be man-compatible; i.e., man rating safety criteria must be applied to systems and functions of the upper stage vehicle which could create a hazard to the orbiter while the upper stage vehicle is in or near the orbiter. The term man-rating, while not strictly defined, means that the safety, i.e., lack of hazards to the Shuttle and Shuttle personnel, has been adequately demonstrated so that the residual risks to personnel are judged to be acceptable. This is, of course, a subjective matter and no definite man-rating criteria can be cited.

On the Saturn S-II and Apollo CSM programs, two successful unmanned flights were the last phases of man-rating a new launch vehicle. It is not clear what the equivalent requirement is for upper stage vehicles, since the mission phases which require man-compatibility are the relatively passive phases of launch, boost, on-orbit deployment and retrieval, deorbit, re-entry, and landing.

The test requirements for man-compatibility must therefore be developed, and must be consistent with the corresponding man-rating requirements on the Shuttle.

One possibility is that a safe unmanned test be performed on the Shuttle, in which one or both propellants are replaced by equivalent fluids which cannot react chemically. For example,  $\text{LO}_2/\text{LH}_2$  vehicles may be launched into orbit and returned to earth using  $\text{LN}_2/\text{LH}_2$ . The liquid nitrogen will provide an adequate simulation of the liquid oxygen, but neither the nitrogen nor the hydrogen on their own, nor in combination, can produce a chemical reaction. Other propellants can be replaced by chemically inert fluids with analogous density, thermal, and other properties. Such a flight test can also be used to satisfy man-compatibility requirements; but it can also be used as a part of the vehicle qualification testing because the Shuttle environment is perfectly reproduced. Such combined testing may prove very cost effective, replacing a large portion of the ground qualification testing, as well as man-rating the vehicle.

An alternative man-compatibility test may consist of launching the upper stage vehicle into orbit as a kick stage, using a booster which exhibits environments at least as severe as the Shuttle. Such a test imposes design constraints on new upper stage vehicles (i.e., the tug/OOS) to make it compatible with the Shuttle orbiter and the other booster.



#### **A.24 BIBLIOGRAPHY**

1. Preliminary Edition of Reference Earth Orbital Research and Applications Investigations, NASA, 15 January 1971.
2. Space Shuttle Program, Proposal No. SD 72-SH-50, North American Rockwell Corp./Space Division, 12 May 1972.
3. Modular Space Station, Phase B Extension, Safety Analyses Report, Final Report No. SD 71-224, North American Rockwell Corp./Space Division, 30 November 1971.
4. Research and Applications Modules (ROM), Phase B Study, Final Report Executive Summary Report No. GDCA-DDA 72-009, General Dynamics/Convair Space Division, 12 May 1972.
5. Shuttle Orbital Applications and Requirements (SOAR), Final Report No. MDC G2546, McDonnell Douglas Astronautics Co., December 1971.
6. In-Space Propellant Systems Safety, Final Report No. SD 72-SA-0054, North American Rockwell Corp./Space Division, 23 June 1972.
7. Space Tug Point Design Study, Final Report No. SD 72-SA-0032, North American Rockwell Corp./Space Division, 11 February 1972.
8. Orbit-to-Orbit Shuttle (Chemical) Feasibility Study, Final Report No. SAMSO-TR-73-238, Prepared for Air Force Space and Missile Systems Organization by North American Rockwell Corp./Space Division, October 1971.
9. Orbital Operations Study, Final Report No. SD 72-SA-0007, North American Rockwell Corp./Space Division, May 1972.
10. Compatibility of a Cryogenic Upper Stage with Space Shuttle, Final Report No. GD CA-BMZ 71-020-7, General Dynamics/Convair Aerospace Div., April 1972. (NASA Report No. CR-120897).
11. Shuttle/Agena Compatibility Study, Final Presentation No. LMSC-D152751, Lockheed Missiles and Space Co., Inc./Space Systems Division, 18 January 1972.



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## APPENDIX B.

### SUPPORTING ANALYSES-DOCKING

This appendix presents supporting analyses performed during Task 2, Analysis of Earth Orbital Shuttle/Modular Space Station Docking Options. It should be read as a technical appendix to Section 3.0 of this volume.

#### B.1 DOCKING DYNAMICS WITH DOCKING PORTS OFFSET FROM THE CENTERS OF MASS

The current experience of docking on the Gemini and Apollo programs has dealt with the situation in which the centerlines of the docking ports were essentially aligned with the centers of mass of the two docking vehicles. This results in minimum angular motions upon contact.

The current configurations of the orbiter and the modular space station result in docking port alignments which are offset from the respective centers of mass, as shown in Figure B-1. This leads to an angular motion of the two vehicles upon initial docking contact, which must be cancelled out by the attitude control systems of the vehicles (or by the manipulator, where used for the final docking, if this has the necessary torque capability). The direction of the angular motions (assuming zero angular rates before contact) will be in the same direction for the two vehicles if the docking port lies between the two centers of mass, (see Figure B-2A), or in opposite directions if both centers of mass are on the same side of the center of mass (see Figure B-2B). The angular velocity of each vehicle depends on the contact velocity, the vehicle mass, moments of inertia and distance of the center of mass from the docking port. The velocities for the two vehicles will in general be different, and if the necessary corrections are not promptly applied by the attitude control systems, contact with the two vehicles with consequent damage will result. The dynamics of the situation, the angular rates and angular excursions reached, as well as the consequences of a control system failure at the critical moment are therefore of interest from the safety point of view, and are examined here for typical situations.

Four cases have been analyzed, using combinations of a large and a small orbiter docking respectively to a large and a small space station. The large orbiter is representative of the fully re-usable orbiter with built-in propellant tanks, as studied in the Phase B Shuttle Study. The small orbiter is representative of the orbiter with separatable propellant tanks, as studied in the Phase B Shuttle extension studies. The large and small space stations represent different stages of build-up, the large one being the built-up 6-man version, and the small being the single module launched initially.

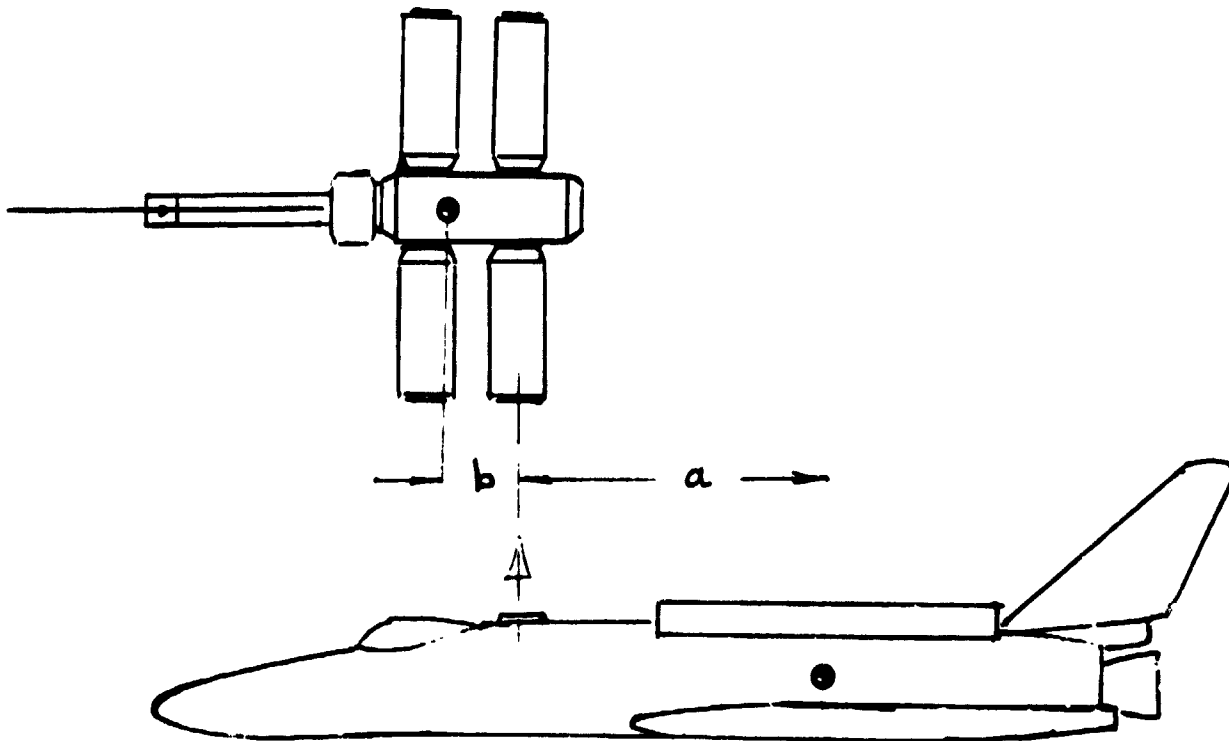


Figure B-1. Typical Orbiter to Station Docking Configurations Showing Relative Positions of Centers of Mass and Docking Ports.

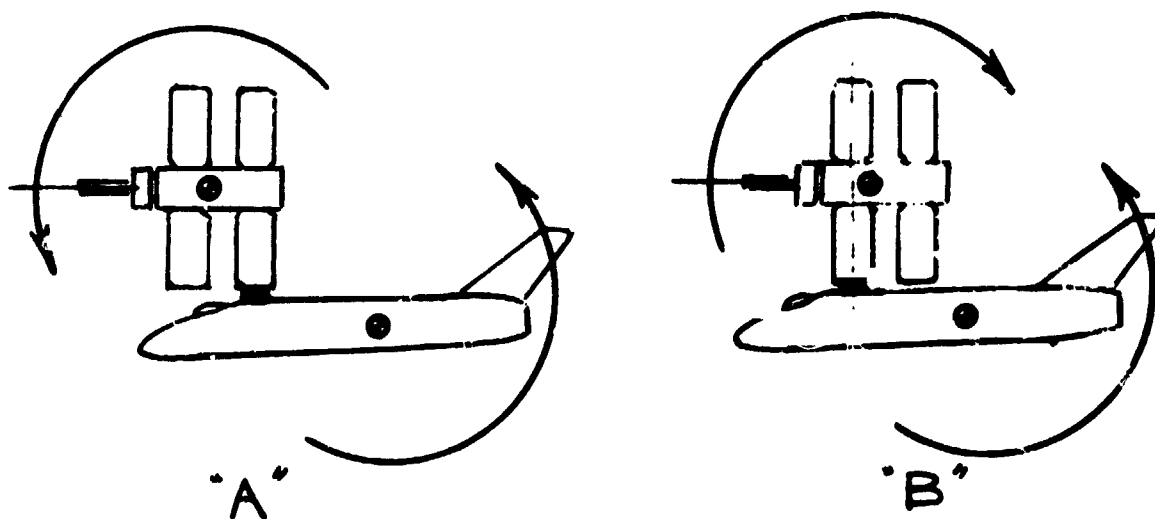


Figure B-2. Direction of Initial Angular Motions Following Docking.

Table B-1 shows the mass properties and relevant dimensions for the four cases (see Figure B-1 for the definition of the dimensions). These properties are typical of orbiters and stations studied in the NR phase B shuttle and station studies.

Table B-1. Mass Properties and Dimensions of Four Cases of Orbiter to Station Docking

<u>Case</u>	1	2	3	4
<u>Orbiter</u>	Large	Small	Large	Small
<u>Station</u>	Large	Large	Small	Small
<u>Orbiter Properties</u>				
Mass, kg x 10 <sup>4</sup> (slugs)	15(10,000)	8(5,500)	15(10,000)	8(5,500)
Moments of Inertia				
kg.m <sup>2</sup> x10 <sup>6</sup> (slug.ft <sup>2</sup> x10 <sup>6</sup> )	26 (20)	8 (6)	26 (20)	8 (6)
"a", m (ft)	21 (71)	21 (71)	21 (71)	21 (71)
<u>Station Properties</u>				
Mass, kg x 10 <sup>4</sup> (slugs)	5 (3500)	5 (3500)	1 (700)	1 (700)
Moments of Inertia				
kg.m <sup>2</sup> x10 <sup>6</sup> (slug.ft <sup>2</sup> x10 <sup>6</sup> )	1.7 (1.3)	1.7 (1.3)	0.13 (0.1)	0.13 (0.1)
"b", m (ft)	4.5 (15)	4.5 (15)	3 (10)	3 (10)

The angular excursion which will be experienced depends on the initial angular velocity and the control authority available from the vehicle attitude control system. This authority differs by orders of magnitude between the orbiter and station. The orbiter uses reaction control jets of 9500 N (2100 lb) thrust on the NR design, and 7100 N (1600 lb) on the MDAC design. The space station jets, on the other hand, are 45 and 90 N (10 and 20 lb) respectively on the NR and MDAC designs, with moment arms smaller than on the orbiter. The capability for applying torques is 150 to 1000 times larger on the orbiter than on the station, and taking the differences in moments of inertia into account, the control authority (expressed as angular acceleration capability) is anywhere from 2.2 to 125 times larger on the orbiter than on the station. The least control authority exists on the large, built-up space station, which has the relatively large moments of inertia, but only 45 to 90 N (10 to 20 lb) jets. This can only produce angular accelerations (in the pitch plane) of about .01 deg/sec<sup>2</sup>.

Because the station control system has the lesser control authority, and hence the greater potential for problems, the remaining analysis is concerned with the station only. Table B-2 shows the angular rates, decelerations, and other parameters of interest for the four cases considered. The docking impact velocity is taken to be 0.3 m/sec (1 ft/sec) and the control moment that can be applied 545 N.m (400 lb.ft).

Table B-2. Angular Motion of Space Station Following Docking  
With Orbiter at 0.3 m/sec (1 ft/sec) and 545 N.m.  
(400 lb.ft) Control Moment

Case	1	2	3	4
Initial Angular Velocity, deg/sec	0.8	0.45	2.1	1.6
Deceleration, deg/sec <sup>2</sup>	0.01	0.01	0.14	0.14
Angular Excursion, deg.	32	10	16	9
Time to Decelerate, sec.	72	39	15	12

The table shows that the worst situation occurs in Case 1, in which a large orbiter docks to a large station. The large inertias involved, transfer a substantial angular momentum to the station, and this turns through a 32 degree angle (assuming that the initial capture latches hold), in 72 seconds, before the motion is arrested. This obviously poses geometric problems, both in the detail design of the docking mechanism itself to allow for such angular misalignments, and in the potential of inadvertent contact between the vehicles.

For the other cases, the combination of inertias may lead to larger or smaller initial angular velocities, but the resulting angular excursions are less.

The above example assumed a docking velocity,  $V$ , of 0.3 m/sec (1 ft/sec) and a control moment,  $M$  of 545 N.m (400 lb.ft). For other values of these parameters the results vary as follows:

- o Angular acceleration  $\propto M$
- o Angular velocity  $\propto V$
- o Angular excursion  $\propto V^2/M$
- o Time to decelerate  $\propto V/M$



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The problems associated with the large angular excursions can thus be considerably alleviated by reducing the docking velocity,  $V$ . For example, at 0.12 m/sec (0.4 m/sec), as planned on the MDAC station, the 32 degrees excursion for Case 1 is reduced to 8 degrees. The excursion is further reduced to about 4 degrees by using the larger control jets of 90 N (20 lb) used in the MDAC station design.

At the docking velocities used by the manipulator system, of 0.03 m/sec (0.1 ft/sec), the problem essentially vanishes, with an angular excursion of 0.3 degrees. This sensitivity to docking velocity and control moments is shown in Figure B-3.

Similar considerations show that the orbiter, with control authority about two orders of magnitude greater than the station, can counteract angular motions practically instantaneously, and does not have this kind of problem.

A serious hazard occurs if the attitude control system fails after capture, but before motion has been arrested and the vehicles stabilized. If this happens, the affected vehicle will continue its angular motion, the docking interface will be broken, and the vehicles will collide with each other. The docking interface will not normally be rigidized until the docking transients have been thoroughly damped, so that the docking port will not at this time be in a configuration to transmit corrective moments applied by the other vehicle's control system. This is a particularly difficult problem if the failure occurs on the station. The orbiter, with its larger control authority, will have inertially stabilized itself practically instantaneously, but the station will keep on moving.

The obvious solution is to rapidly undock and back the orbiter away from the station so as to avoid damage. In such a case, however, if the station control system problem cannot be corrected, it may be impossible to ever re-dock to the station again, and the station would have to be abandoned, with an emergency EVA evacuation by the station personnel.

The recommended solution is to fly the orbiter so that it follows the space station motion. This would involve complex sensing devices or procedures, to track the station angular motions, and possible minimum impulse attitude adjustments on the orbiter. This maneuvering would continue until the angular motions of the two vehicles have been damped out enough to enable rigidizing to be performed while the two vehicles are still rotating in inertial space. Once rigidizing has occurred, the orbiter can transmit moments through the docking port, and stop the motion of both vehicles.

If the failure is in the control system of the orbiter, the suggested corrective procedures can be applied in reverse, with the station tracking the orbiter motion until the two vehicles can be rigidized and the motion arrested. The corrective action will in this case be much slower, and the sensing devices could be simpler, possibly even visual inspection.

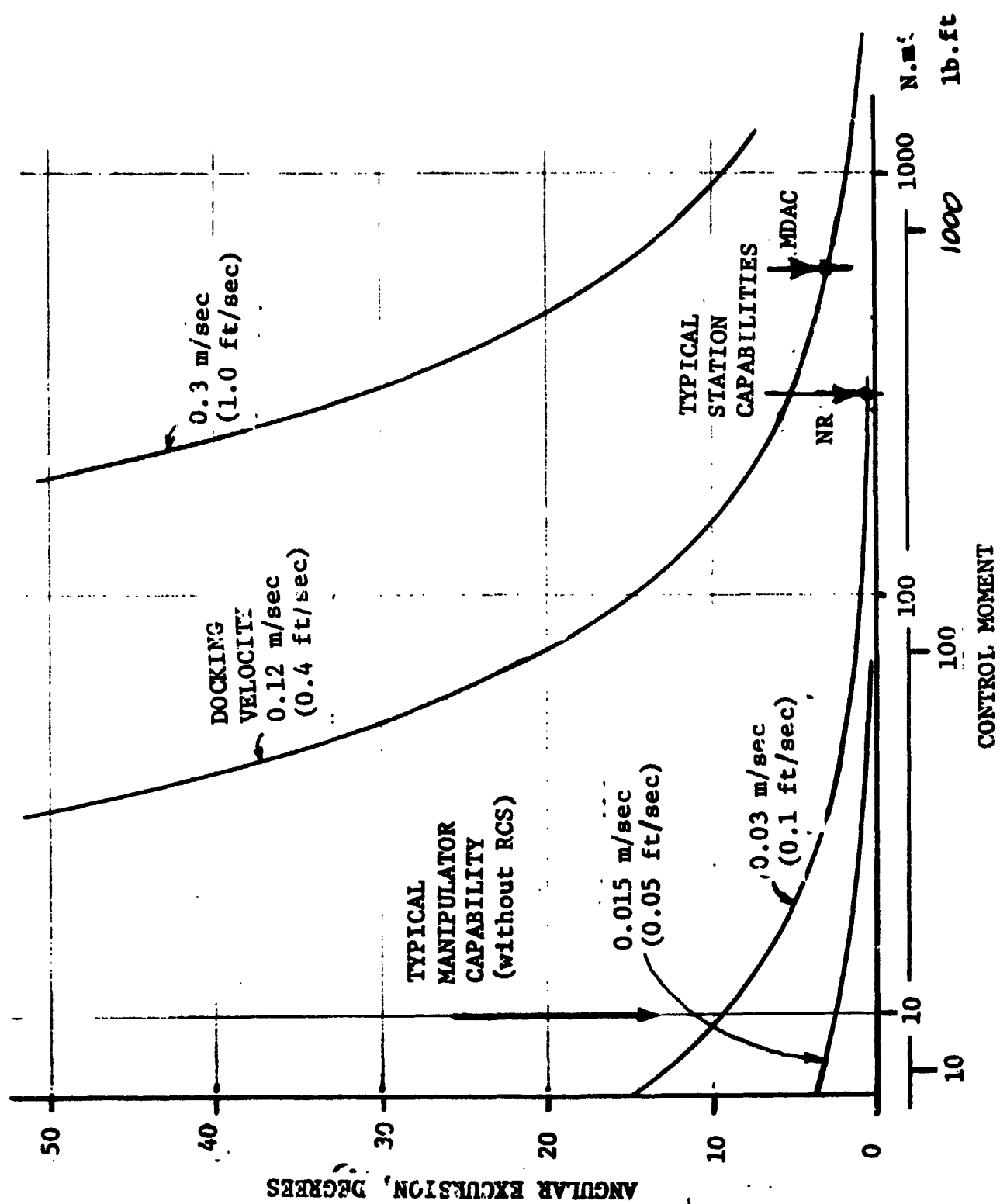


Figure B-3. Angular Excursion of Typical Space Station Following Initial Docking Capture.



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If the manipulators are used for docking, then the same problem can arise, and the same corrective procedures applied, if the control system failure is in the control system of the manipulator. In this case, however, the motion is much less than for direct docking because of the dynamics (as shown above), the manipulators could possibly provide some damping torques, and the station attitude control system provides a back-up to the manipulator control system. This problem is therefore not very severe where manipulators are used for docking.

## B.2 NON-COLLISION DOCKING APPROACH VECTOR

A potential hazard exists when two docking vehicles approach each other on a line-of-site course, as usually planned for the final docking maneuver. This is essentially a collision course, and if a control system failure occurs on the active vehicle, so that the final velocity reductions cannot be achieved, a collision will occur at a velocity higher than the capability of the docking system, with consequent damage.

In order to avoid this hazard, a new procedure is suggested here, which avoids the possibility of an inadvertent collision at too high a velocity. This consists of aiming the approach velocity vector not at the docking port of the target vehicle, but at an imaginary "pseudo-target" some distance to one side of the target vehicle. This is illustrated in Figure B-4. The pseudo-target is sufficiently to the side of the target vehicle that if a control system failure should occur, the active vehicle passes by the target without the possibility of contact. Some margin may be allowed for possible rotations and errors.

This non-collision approach vector is maintained while the velocity of the active vehicle is above the docking system attenuation capability. Deceleration through the various "braking gates" occurs along this direction. The velocity vector is only changed to be on a line-of-site, or collision, course when its velocity has been reduced to within the docking system attenuation capability. If a control system failure occurs now, the docking system can withstand the collision without damage.

The method is illustrated in Figure B-4. This shows how the original vector and the pseudo-target are selected, so as to avoid potential contact, and how the final velocity correction is applied to bring the two vehicles together at 0.12 m/sec (0.4 ft/sec), the assumed docking velocity. The final directional change must be made at the correct time, when the two docking systems are opposite each other.

A number of options are available in applying this procedure. Firstly, the active vehicle may be oriented orthogonally to the target vehicle, so that it is moving crab-wise until the final velocity change. This is the way illustrated, and does not require a re-orientation of the vehicle, but only of its velocity vector. Alternatively the vehicle may be oriented in the direction of the approach velocity, i.e., towards the pseudo-target, and change orientation at the same time as the velocity vector.



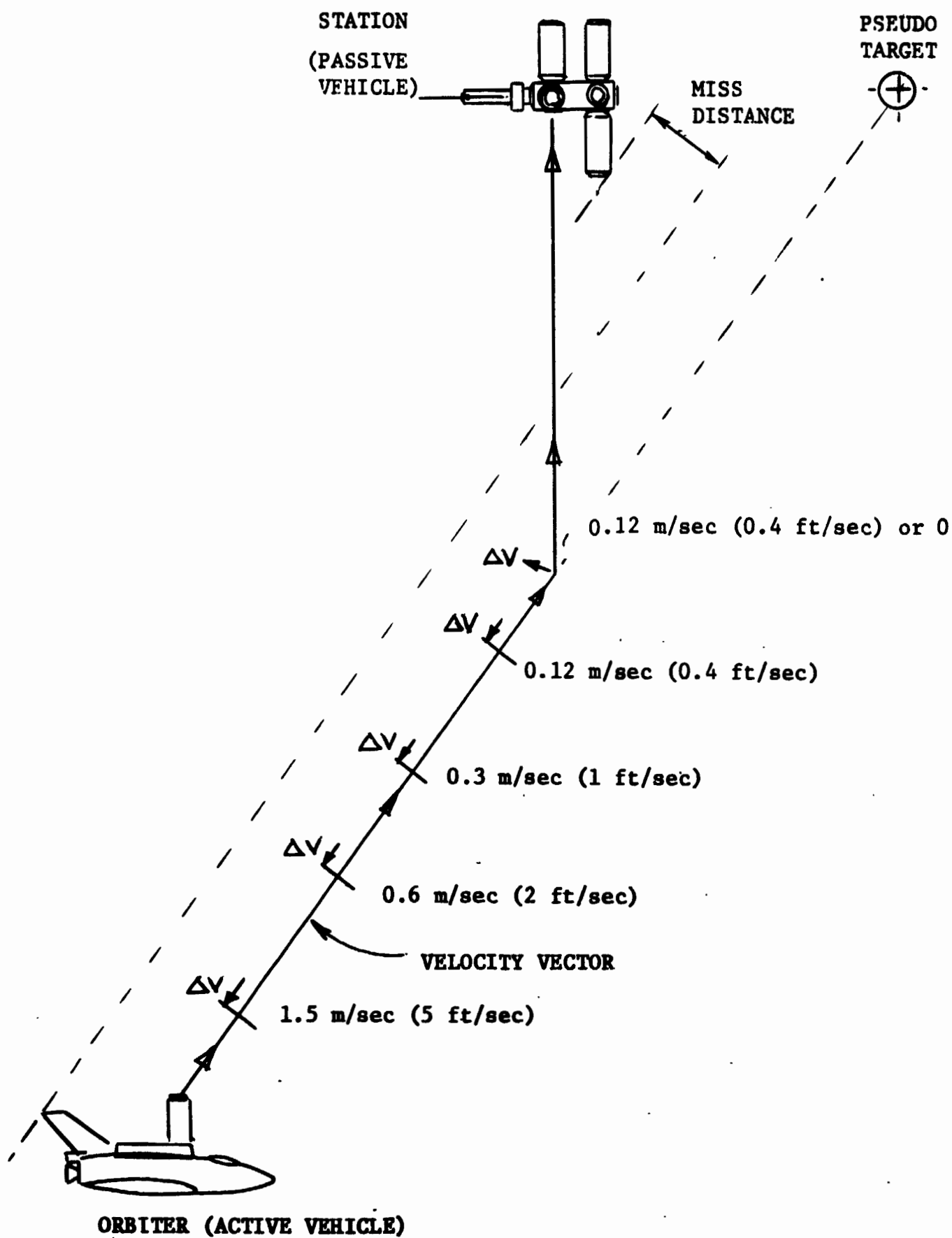


Figure B-4. Non-collision Docking Approach.



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The other option refers to the final braking maneuver. In the figure shown, the velocity is reduced to 0.12 m/sec (0.4 ft/sec) while still pointing towards the pseudo-target, and a relatively small correction applied when opposite the target, which does not change the magnitude of the velocity, but only its direction. Alternatives to this consist of making a combined final correction in the final braking gate, (which is relatively complex in timing and direction, but minimizes propellant usage); or first coming to an absolute halt opposite the target, and then accelerating on the final line-of-site vector (which simplifies the procedure, but increases propellant usage).

Two potential difficulties can be foreseen with this procedure. Firstly, the guidance of the vehicle towards a non-existent pseudo-target is a more complex maneuver than a simple line-of-site approach. It may be found, however, that a "bias" can be introduced simply and reliably into the optical system. The angle of view of the target vehicle will continually change, however.

Secondly, the attitude control system programming is more complex, possibly requiring more propellants, and more complex computer aided controls. If the orientation of the active vehicle is maintained constant, the braking maneuvers require simultaneous firing of several jets in a pre-determined but constant ration, and this is a non-optimum use of the system.

The safety advantages, of completely avoiding the possibility of an inadvertent collision at a velocity to cause damage, must be evaluated against the potential disadvantages pointed out. This preliminary evaluation indicates that the advantages may be worth the penalties involved. A fuller evaluation of the method, including simulations with visual displays, should be made.

### B.3 BIBLIOGRAPHY

1. Preliminary Design of a Shuttle Docking and Cargo Handling System Concept Review and Selection. Martin Marietta Corp., Contract NAS 9-11932, 8-16-71.



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## APPENDIX C

### SUPPORTING ANALYSIS-ON BOARD SURVIVABILITY

This appendix presents supporting analysis performed during Task 3, Analysis of Traffic Patterns, Escape Routes, and Compartment Isolation. It should be read as a technical appendix to Section 4.3 of this volume.

#### C.1 Flood Flow Rate

A rapid loss of pressure in an inhabited pressure volume can result in loss of personnel if evacuation of the compartment to a succor volume, the donning and utilization of pressure suits, or repair of the leak cannot be accomplished in sufficient time. One method proposed in the text, to enhance crew reaction time to cope with a depressurization emergency, involved the flooding of the affected volume with atmosphere at a rate which is at least equivalent to that at which it is being lost to space. This flooding operation need not be initiated until the atmosphere pressure level is approaching the minimum, below which the crew cannot function or survive. This level is nominally estimated to be approximately 8 psi. If the crew has evacuated the compartment and it is necessary to re-enter the compartment after it has dropped below the minimum acceptable pressure, the flood flow rate of atmosphere required must exceed the loss rate.

The atmosphere flood flow rate required to maintain compartment pressures between  $4.82 \times 10^4 \text{ n/m}^2$  (7 psia) and  $10.12 \times 10^4 \text{ n/m}^2$  (14.7 psia), as a function of the hole diameter through which atmosphere is being lost to space, is shown in Figure C-1. The flood flow rate is independent of the compartment volume.

From the chart it can be seen that, for a 2.54 cm (1 in) diameter hole, a flood flow rate of approximately 7.7 kg/min (17 lb/sec) is required to maintain the atmospheric pressure at  $10.12 \times 10^4 \text{ n/m}^2$  (14.7 psia). The reaction time gained for any reserved quantity of flood flow atmosphere would be added to the time involved to reduce the affected compartment pressure to the level at which flood flow is initiated to arrive at the total afforded reaction time. For example, 77 kg (170 lb) of stored atmosphere can extend the crew reaction time to cope with a 2.54 cm (1 in) hole in a  $56.8 \text{ m}^3$  (2000  $\text{ft}^3$ ) orbiter crew/passenger compartment by 10 minutes; i.e., from 6 to 16 minutes.

#### C.2 EMERGENCIES/CONFIGURATION OPTIONS RELATED TO EVA AND IVA

The inability to open or close hatches during IVA (Intravehicular Activity) or EVA (Extravehicular Activity) is a potential hazard which affects orbiter, station, and sortie module escape routes and compartmentation requirements. IVA is defined as suited crew operations within the structural confines of a vehicle while EVA is suited crew operations outside the structural confines of the vehicle.

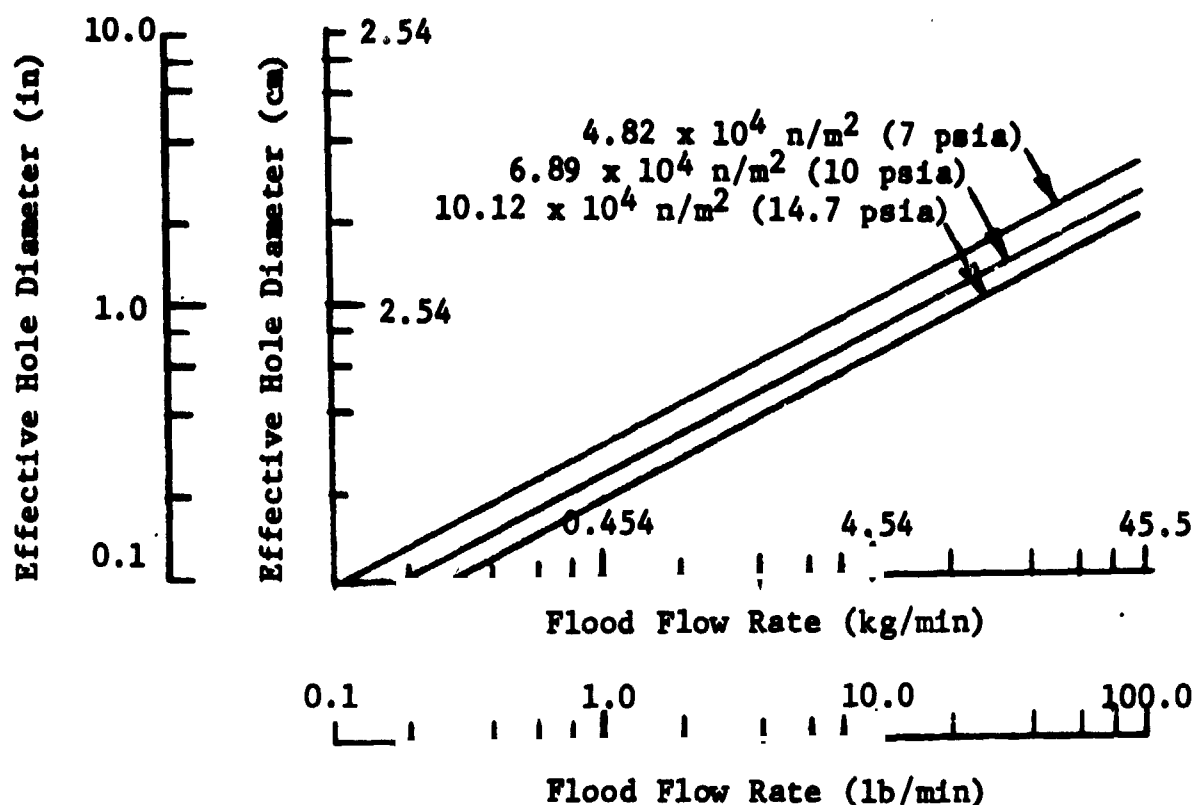


Figure C-1. Atmosphere Flood Flow Rate vs. Hole Size

The performance of IVA and EVA during a time in which other crewmen are unsuited, requires airlock capability within the vehicle. The various configuration options which can result from the most simple airlock configuration (an airlock with two hatches) when an inoperative hatch (inability to open or close) is considered, are shown in Figure C-3 for EVA and Figure C-2 for IVA. The inability to open an external hatch in an airlock from which EVA egress was performed is not considered credible, and is therefore not accounted for in the assessment of impact because the hatch, after initial opening, would normally be left open during the performance of EVA. Reference is made to Table C-1 for typical IVA and EVA operations.

Configuration alternatives, shown with hatches and volumes which are in addition to the basic configuration drawn with dashed lines, range from simply back to back or redundant hatches within the baseline airlock to multiple completely independent and redundant airlocks.

Examination of the EVA composite configurations of Figure C-2, the resulting configuration when the hatch and independent volume requirements are combined for inability to open or close a hatch, shows that a minimum of four hatches within the airlock, or four hatches combined with the airlock and an additional pressure volume are required to cope with an inoperative airlock hatch during EVA.

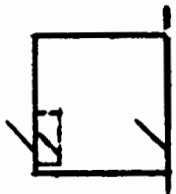
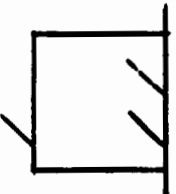
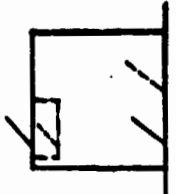
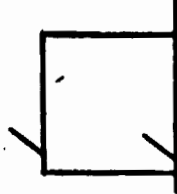
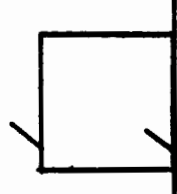
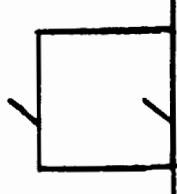
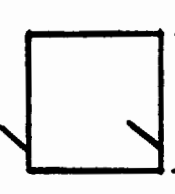
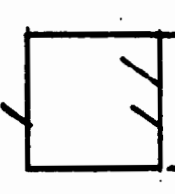
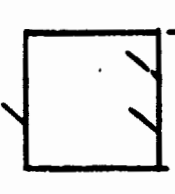
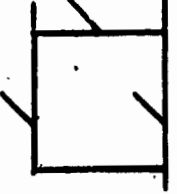
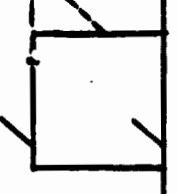
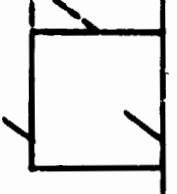
Basic Configuration	Option	Situation		Composite Configuration
		Failure to Close External Hatch	Failure to Open Internal Hatch	
<div> <div>External Hatch</div> <div>EVA Airlock</div> <div>Internal Hatch</div> </div>	A			
	B			
	C			
	D			

Figure C-2. Impact of Inoperative Airlock Hatch During EVA

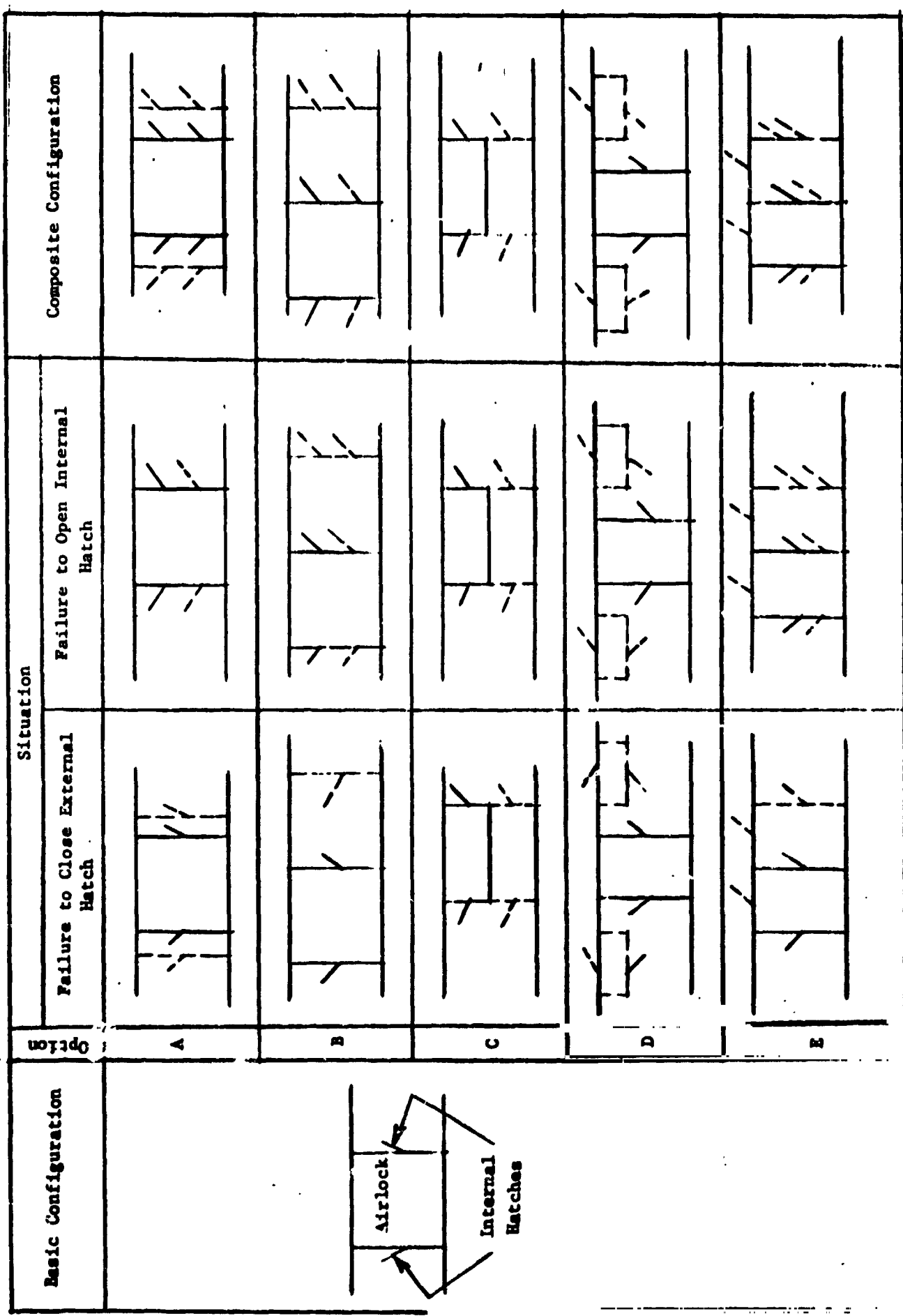
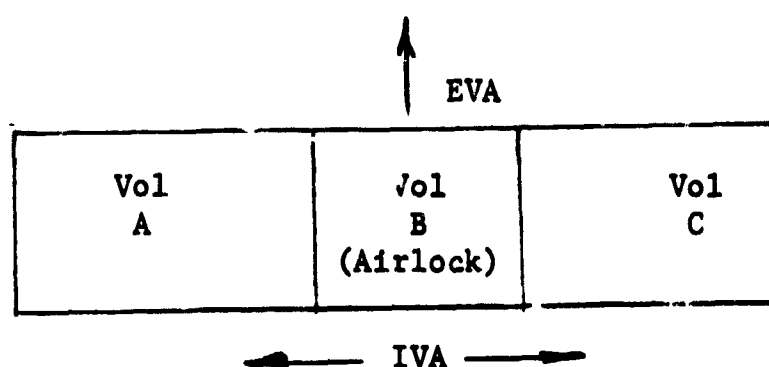


Figure C-3. Impact of Inoperative Airlock Hatch During IVA

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Table C-1. Typical Operations for Performing IVA or EVA



<u>Sequential Operation</u>	<u>Operation Applicability</u>	
	<u>IVA</u>	<u>EVA</u>
Enter Airlock	X	X
Don Pressure Suits (Less Helmet and gloves)	X	X
* Don Pre-Breath Unit	X	X
* Perform Pre-Breathing (Approximately 3 Hours)	X	X
Don PLSS or Attach Umbilical	X	X
Close Airlock Hatches	X	X
* Doff Pre-Breath Unit	X	X
Don Helmet and Gloves	X	X
De-Pressurize Airlock	X	X
Open EVA Hatch		X
Open IVA Hatch	X	
Exit and Perform EVA		X
Exit and Perform IVA	X	
Enter Airlock	X	X
Close EVA Hatch		X
Close IVA Hatch	X	
Repressurize Airlock	X	X
Open IVA Hatches	X	X
Doff Suits and PLSS or Detach Umbilical	X	X
End IVA or EVA Sequence	X	X

\* Required only for 3.7 psig suits, pre-breathing is not required for 8 psig suit.



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A similar evaluation of the impact of an inoperative hatch during IVA operations is shown in Figure C-3. A minimum of four hatches on two adjacent airlocks or six hatches, two pairs of which are back to back in a single airlock, are required for protection against an inoperative hatch during IVA. A unique alternate method for performing IVA is, however, available as can be seen from Option D. In this option an EVA route is used as a backup for IVA. The primary disadvantage with this option is that it requires six hatches and three independent airlocks. An alternate configuration which can employ use of an EVA route for IVA backup is shown in Option E. As can be seen from the chart, this option requires seven hatches and two independent airlocks.

### C.3 TEMPERATURE AND PRESSURE EFFECTS OF FIRE

During the analysis of the impact of a fire/toxic environment on vehicle configuration, subsystems, and operation, several questions arose which required further analysis. These are (1) what temperature range can be reached in a compartment of given volume if a fire in the compartment is permitted to burn until it is extinguished by the gradual depletion of oxygen? and (2) if it were required to limit the thermal energy allowable in a given compartment to control the potential effects of a fire, what is the relationship between available thermal energy, compartment volume, and produced heat and pressure.

A simple calculation, which assumed that a combustible source with the thermal capacity approximately that of coal  $33 \times 10^6$  Joules/kg (15000 btu/lb) was burned in a compartment until all oxygen in the compartment was depleted, showed that the temperature in the compartment could approach  $2573^\circ\text{K}$  ( $4500^\circ\text{F}$ ) if all the generated heat were absorbed by the atmosphere.

This value is well beyond the survival capability of the structure and subsystems of any vehicle. Although in a real situation, the generated heat would also be absorbed in the structure and other material and partially dissipated to space, the magnitude of the feasible temperature and the possibility that the fire could be of sufficiently rapid combustion to render heat absorption rates of media other than the atmosphere negligible leads to the conclusion that letting a fire burn out from lack of oxygen is not acceptable.

The effect of releasing a given quantity of thermal energy into a known compartment volume, which relates to the second question, is shown in Figure C-4. As shown on the chart, the pressure of a typical volume for the orbiter crew/passenger compartment,  $566 \text{ m}^3$  ( $2000 \text{ ft}^3$ ), would be increased between  $7 \text{ kn/m}^2$  (1 psi) and  $14 \text{ kn/m}^2$  (2 psi) and the temperature increased by  $283^\circ\text{K}$  ( $50^\circ\text{F}$ ) from  $294^\circ\text{K}$  ( $70^\circ\text{F}$ ) to  $322^\circ\text{K}$  ( $120^\circ\text{F}$ ) for a thermal input of  $2.1 \times 10^6$  Joules ( $2 \times 10^3$  btu's). The temperature limit of  $322^\circ\text{K}$  ( $120^\circ\text{F}$ ) is indicated because it is estimated that above this temperature crew evacuation from the compartment would be required. Although the pressure increases shown do not appear large, structural damage can occur if these potential increases are not accounted for in design. A fire isolatable compartment, which requires a slight delta pressure between it and the affected volume to prevent smoke and fume contamination can also be rendered ineffective with such slight pressure deltas.



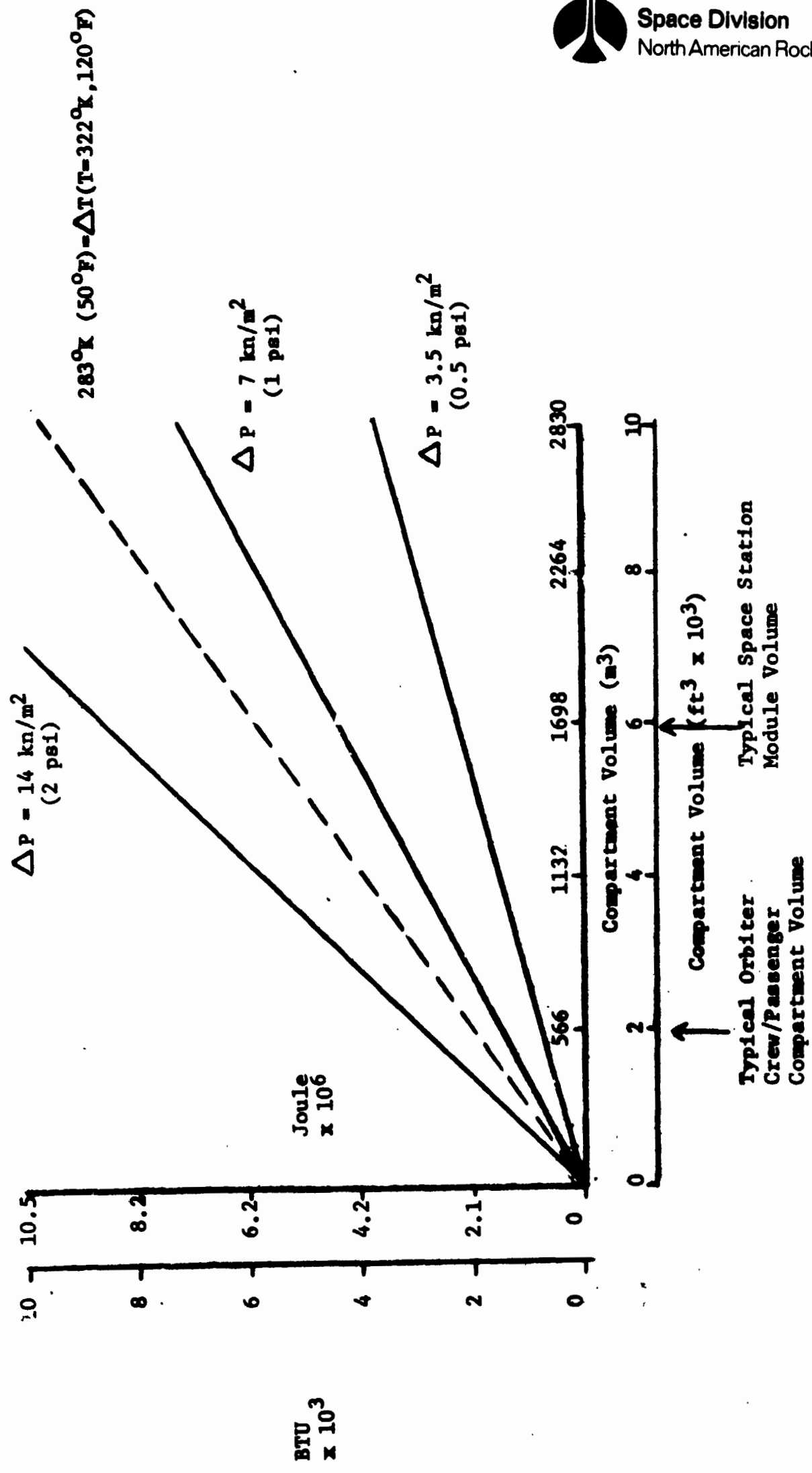


Figure C-4. Relationship of Thermal Energy to Volume, Pressure, Temperature

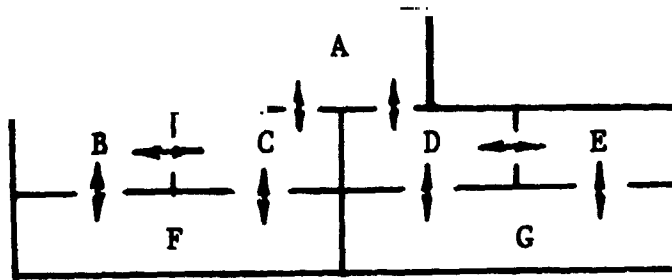
#### C.4 FALLIBILITY OF DUAL EGRESS CRITERIA

Concern over the possible entrapment of personnel in a volume due to an emergency in the volume which has blocked the only egress path to safety led in this study, as well as in previous studies to a dual egress criterion. In addition to providing for dual shirtsleeve egress capability, the prevention of crew isolation through forced egress into non-common volumes is inherent in its intent.

The dual egress criterion as expressed in a previous \*safety study performed for MSC is as follows:

"Each compartment should have a minimum of two escape routes which should not terminate in a common compartment"

A compartmentation arrangement which satisfies this criterion is shown in the diagram below.



It can be seen from the diagram, however, that even though the dual egress criteria is satisfied as stated, personnel can still become isolated from one another. An emergency in compartment A which blocks either egress opening divides the vehicle into two parts in which compartments B, C, and F become isolated from compartments D, E, and G. These compartments can be made accessible to one another if an access route or opening were provided between compartments C and D or F and G.



#### C.5 PASSENGER TRANSFER TIME - AIRLOCK TO CREW/PASSENGER COMPARTMENT

The recommended approach to cope with loss of pressurization in the crew/passenger compartment of the baseline orbiter configuration, as identified in section 4.3.3.3 of this report, is for the passengers to egress to the airlock while the crew dons pressure suits (which do not require pre-breathing) and proceeds to perform an abort from the depressurized compartment.

Because an orbital abort may require in excess of 6 hours for orbital phasing with and landing at a CONUS (Continental United States) landing site and may result in normal entry maneuver, and landing acceleration loads approach 3 g's, passenger abort in the airlock requires that the airlock be fitted with emergency type life support and passenger restraint provisions. Reference is made to Figure 4.3.3-5 for one concept, previously identified and discussed in section 4.3.3-3, of providing emergency restraints within the airlock. Because of the questionable capability of emergency type restraint devices, such as the hammock type employed in the referenced figure, to limit and control directional body excursions to prevent crew injury during an emergency landing in which impact and braking accelerations will be approximately double than those anticipated for normal entry and vehicle maneuvers, the recommendation was made to return the passengers to their respective landing positions in the crew/passenger compartment after the orbiter re-enters the sensible atmosphere and the cabin is re-pressurized to a habitable environment.

This recommendation is based on an assessment of the time available, prior to landing, to transfer the passengers from the airlock to their seats in the passenger compartment. The maximum altitude at which the transfer can be made is that which can physiologically sustain the passengers and permit their functioning in a shirtsleeve environment. This criteria is satisfied only with an atmospheric pressure of approximately  $5.5 \times 10^4 \text{ n/m}^2$  (8 psi) or above which corresponds not only to an altitude of 4500 m (1500 ft), but to the nominal operating pressure level for IVA/EVA suits currently under development, which do not impose a pre-breathing requirement.

The time available to transfer the passengers from the airlock to the passenger compartment is, therefore, equivalent to the difference in time between that when the orbiter has descended to 4500 m (15,000 ft) and the event of touchdown. A typical orbiter descent timeline, which uses the nominal vehicle descent values of a 15 degree bank angle and a lift to drag ratio of seven (7) is shown in Figure C-5. As can be seen from the curve an altitude of 4500 m (15,000 ft) is achieved approximately 4 to 5 minutes prior to landing. This time is estimated to be sufficient for the personnel transfer provided that a time consuming period of pressure equalization between the airlock and passenger compartment is not required at the time of transfer. The need for special pressure equalization procedures at the time personnel transfer is required can be eliminated if, when the abort is initiated or at a sufficient time before initiation of personnel transfer, pressure within the airlock is reduced to  $5.5 \times 10^4 \text{ n/m}^2$  (8 psi). Transfer would then be initiated upon an indication, via a sensor, that pressures within the two compartments were equalized.

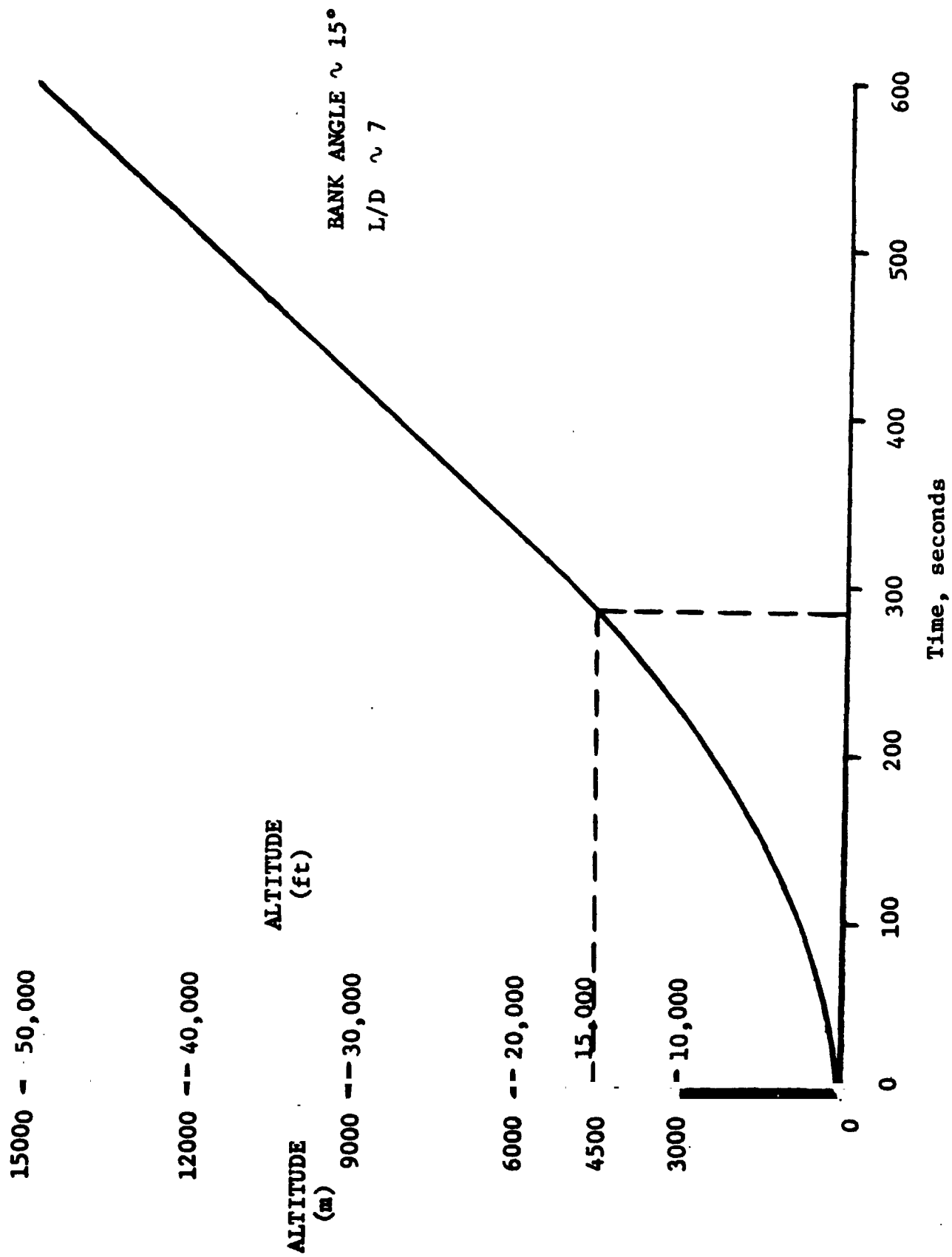


Figure C-5. Typical Orbiter Descent Timeline



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#### C.6 BIBLIOGRAPHY

1. Systems safety Guidelines of New Space Operations Concepts, Space Shuttle System Safety. Contract NAS 8-25576, LMSC-A968322, 1971.
2. Space Station Safety Study, Contract NAS 9-9046. Boeing D2-113070-9, January 1970.
3. Study of Damage Control Systems for Space Station and Preliminary Design of a Space Station Simulator. Contract NAS 1-10184, McDonnell Douglas, MDC G2156, March 1971.

## APPENDIX D

### HAZARD/EMERGENCY ANALYSES

#### 1.0 INTRODUCTION AND SUMMARY

This appendix of the Final report contains analyses of the hazards or emergencies identified during the study. The hazards/emergency analysis performed, with the requirements and guidelines that were developed, are contained in five sections, corresponding to the five tasks performed in the study. Each section is divided into subsections, according to the subtasks of each of the five tasks.

The hazards and emergencies identified are specific to the study tasks, and must not be interpreted as a complete list of hazards or emergencies associated with the shuttle, shuttle payloads and space station. In particular, the hazards/emergencies considered are those that can occur in orbit only, in accordance with the scope of the study. Hazards/emergencies associated with prelaunch, launch, boost, deorbit, reentry and landing are not considered.

The hazards/emergencies which were analyzed are generalized situations rather than hazards or emergencies specific to particular hardware, designs or operations. For example, each separate fluid tank presents individual hazards, according to its contents, pressure, volume, location, etc. All these hazards, however, are grouped into explosion, corrosiveness, and toxicity hazards, without specifying the severity of each hazard associated with each tank. This was done for two reasons: firstly, to make the total number of hazard/emergency analyses for the total study manageable; and secondly, so as to make the resulting requirements and guidelines applicable irrespective of changes to the specific design concepts current at the time of the analyses.

The requirements and guidelines which were generated were carefully worded so as to satisfy three criteria that were considered very important. These criteria are that the requirements and guidelines should:

- (a) be verifiable--i.e., it should be possible to unambiguously verify whether each requirement or guideline has been met in the design or in the planned operations. Ambiguous or non-verifiable words such as "to the maximum extent possible" or "adequate" have therefore been avoided.
- (b) meet the mathematician's "necessary but sufficient" criterion--i.e., they should specify every condition that must be met to satisfy the safety objective, but they should not specify more than is required for safety. The latter point is particularly important since the tendency is to select particular design or operational solutions which restrict the designer's choice, rather than stating only the requirement in general terms.
- (c) be written in precise and unambiguous language, suitable for incorporation into preliminary requirements specifications for Phases B or C.

A listing of the hazards and emergencies which have been identified and analyzed for each of the five tasks in the study is contained in Sections 2.5, 3.7, and 4.1 of this volume. The disposition of each hazard/emergency is also indicated in these tables for the first two tasks. Since the purpose of the third task was not to eliminate or reduce the emergencies considered, but to provide the on-board survival following their occurrence, there is no corresponding disposition of these emergencies.

Hazards/emergencies can be disposed of into one or more of the following categories:

- ° Resolved Hazard. The recommended requirements and guidelines, when implemented, either eliminate the possibility of the hazard occurring; or reduce the potential effects of the hazard, if it does occur, so that neither injury to personnel nor damage to equipment can result.
- ° Residual Hazard. The recommended requirements and guidelines, when implemented, do not entirely eliminate the potential occurrence of the hazard, or the possibility of injury to personnel or damage to equipment, however low the probability. Residual hazards are further classified as Acceptable Risks, SRT Requirements, and Unresolved Safety Issues.
- ° Acceptable Risk. A residual hazard is an acceptable risk if the risk--i.e., the probability of occurrence and the potential damage that may result--are small enough after the recommended requirements and guidelines have been implemented, that no further safety measures need be taken to further reduce the risk.
- ° Supporting Research and Technology (SRT) Requirements. It is not possible, with the present state of technological knowledge to determine if the hazard can be adequately resolved (Resolved Hazard), or if the risk can be sufficiently reduced (Acceptable Risk). SRT requirements can be identified, however, which will reduce the hazard to an acceptable level, or determine the extent of the hazard.
- ° Unresolved Safety Issue. The nature of the hazard is such that no practical requirements, guidelines or SRT requirements have been identified which can resolve the hazard or reduce it to an acceptable risk. Continuous review is necessary of these unresolved safety issues during a program to reduce the risk as much as possible by design and other means.

## 2.0 TECHNICAL APPROACH

The main purpose of performing hazards/emergency analyses is to identify safety requirements and guidelines in a methodical way. The format used was developed from hazard analyses performed on the Phase B Space Station and Shuttle contracts at NR/SD, and is illustrated in Figure 2-1. An explanation of the various features of this form follows. The item numbers below refer to the circled numbers in the figure.

1. PROGRAM. An X indicates that at least one recommended requirement or guideline from this hazard/emergency analysis is applicable to the appropriate program (Shuttle, Sortie or Station), and appears respectively in Volumes IV or V of this report.
2. NO. Each hazard/emergency analysis is numbered sequentially with three numbers in a decimal system. The first two numbers refer to the task and subdivision of the task in accordance with Table D-1, and the last three digit number is the sequential number for the hazard/emergency analyses within the subtask. (e.g., 2.1.003 refers to the third hazard/emergency analysis for the first subdivision of task 2).
3. DATE. This is the date on which the analysis was initiated. It is included as a guide to the reader as to the general concepts and programs which were current at the time of the analysis.
4. HAZARD/EMERGENCY. This describes the hazard or the emergency which is being considered, and contains identical wording as in Volume II.
5. SOURCE. This cross-references to the section in Volume II in which the hazard or emergency is identified and/or discussed. The Roman numeral identifies the report volume (normally Volume II) and the subsequent number the specific section or sections of that volume.
6. ASSUMPTIONS. The validity of each hazard/emergency analysis is dependent on various assumptions. While it is very difficult at times to recognize that certain assumptions are implicit in an analysis, a strong effort has been made to identify and state all the relevant assumptions here. In this way each analysis can be reviewed at any time, and if the assumptions are still applicable, then the requirements and guidelines are still applicable; if there have been program changes so that the assumptions are no longer valid, then the whole hazard/emergency analysis should be reviewed.



Table D-1. Numbering System for Hazard/Emergency Analyses

Hazard/Emergency Analysis Number	Task	Subdivision
1.1.XXX	Hazardous Payloads	Upper stage vehicles
1.2.XXX	"	Hazardous Fluid Vessels
1.3.XXX	"	Cargo handling and transfer
2.1.XXX	Docking	Hazards common to all systems and modes
2.2.XXX	"	Hazards specific to the direct docking system
2.3.XXX	"	Hazards specific to the extendable tunnel docking system
2.4.XXX	"	Hazards specific to the manipulator docking system
2.5.XXX	"	Hazards specific to free flying module docking mode
3.1.XXX	On-board Survivability	--

HAZARD/EMERGENCY ANALYSIS															
<table><tr><td rowspan="3">PROGRAM ①</td><td>SHUTTLE</td><td></td></tr><tr><td>SORTIE</td><td></td></tr><tr><td>STATION</td><td></td></tr></table>		PROGRAM ①	SHUTTLE		SORTIE		STATION		<table><tr><td>NO.</td><td>②</td></tr><tr><td>DATE</td><td>③</td></tr></table>			NO.	②	DATE	③
PROGRAM ①	SHUTTLE														
	SORTIE														
	STATION														
NO.	②														
DATE	③														
HAZARD/EMERGENCY ④		SOURCE ⑤													
ASSUMPTIONS ⑥															
POTENTIAL EFFECTS ⑦															
REQUIREMENTS & GUIDELINES ⑧		CODE ⑨	RGD REF. ⑭												
		⑩ X	⑪ X	⑬ X											
		⑫ X	⑬ X												
RESOLVED HAZARD ⑮		RECOMMENDED (X) OR NOT ( )													
RESIDUAL HAZARD ⑮		NO. OF HRPS (1, 2, 3, 4)													
		REQUIREMENT (R) OR GUIDELINE (G)													
		PREVENTIVE (P) OR REMEDIAL (R)													

Figure 2-1. Hazard/Emergency Analysis Format



In addition, assumptions which are applicable to all hazards/emergency analyses for a particular task are defined in the baseline model for that task.

7. **POTENTIAL EFFECTS.** The potential effects of the hazard or emergency are described briefly. Generally only the immediate effects are described. Since a good definition of the system is not available, configurations and designs can always be imagined in which even a minor effect could lead, by a chain of events, to a catastrophic situation. Therefore no attempt was made, in general, to trace all potential effects, since in every case these would have been the same: loss of personnel and loss of vehicle. Where the immediate effects could be predicted, however, these were described, as far as possible, in terms of injury or loss of personnel or of damage or loss of equipment. The objective of the hazard/emergency analysis, of course, is to identify practical requirements and guidelines which would either make the occurrence of the hazard or emergency impossible or extremely unlikely, or which would reduce the potential effects so that injury or damage will not result even if the hazard or emergency occurs. The potential effects therefore refer to before the requirements and guidelines are implemented.
8. **REQUIREMENTS & GUIDELINES.** Individual requirements and guidelines are identified here which will either prevent the hazard or emergency, make it less likely, or reduce the potential effects. The difference between a requirement and a guideline is as follows:
  - o A requirement is regarded as a "must implement" item from the safety point of view. It eliminates an appreciable element of risk from the total spectrum of risks associated with the particular hazard or emergency. If recommended, a requirement is therefore not considered as an item to be rejected for cost, weight or similar reasons, since it significantly impacts safety.
  - o A guideline is regarded as a "strongly recommended" item from the safety point of view. It does not eliminate any appreciable element of risk, although it may reduce the occurrence or the resulting effects of the hazard. The increase in safety from a guideline in certain circumstances may not be commensurate with the penalties of implementing it, and therefore it may be traded off against cost, weight, etc. There is, in all cases, a safety penalty (in the form of exposure to some additional risk) whenever a guideline is not implemented, and this must be recognized whenever such a decision is taken.



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The requirements and guidelines are numbered sequentially in each hazard/emergency analysis. A letter behind the number indicates that the requirement or guideline is common to more than one hazard/emergency analysis. Such repeated requirements and guidelines are listed by the identifying analysis in front of each task. In a methodical perusal of the requirements and guidelines, the reader can therefore avoid re-reading items identified by a letter.

9. CODE. A four digit code identifies certain judgments made against each requirement or guideline. The four digits of the code are explained in items 10 through 13 below. Whenever a requirement or guideline appears in more than one hazard/emergency analysis, the identical code is used.
10. RECOMMENDED (X) OR NOT (-). For each hazard/emergency analysis a set of the identified requirements and guidelines is recommended (by an X in the code). This recommended set is considered the best set of requirements to deal with the hazard or emergency. State-of-the-art, complexity, cost and weight were considered in arriving at the recommendations.

Where a particular requirement or guideline is not recommended (indicated by a - sign), this was done on one of several grounds:

- (a) It is not practical (e.g., because it severely interferes with the mission objectives).
- (b) It is beyond the current state-of-the-art.
- (c) An alternative and preferred means of dealing with the particular risk exists in another recommended requirement or guideline.
- (d) Only a negligible increase in safety results.
- (e) New hazards are introduced which reduce or nullify any increase in safety.

It should be noted that in many cases an item identified as a requirement is not recommended. This is done on one of the above grounds, and does not represent an inconsistency. It may represent a judgment that it is not practical or within the state-of-the-art to implement, or that the risk is eliminated by another (recommended) requirement.

Only recommended requirements and guidelines are included in Volumes IV and V.

11. NO. OF HRPS (1, 2, 3, 4). HRPS refers to the Hazard Reduction Precedence Sequence of the NASA OMSF Safety Program Directive No. 1, Revision A (SPD-1A), 1700.120, December 12, 1969. This is quoted verbatim as follows:

"HAZARD REDUCTION PRECEDENCE SEQUENCE

Actions for reducing hazards identified in above analyses shall be, in order or precedence, as specified in paragraphs 1 through 5 of these requirements.

1. Design for Minimum Hazard

The major effort throughout the design phases shall be to insure inherent safety through the selection of appropriate design features as fail safe, redundancy, and increased ultimate safety factor.

2. Safety Devices

Known hazards which cannot be eliminated through design selection shall be reduced to the acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment.

3. Warning Devices

Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals or of improper personnel reaction to the signals.

4. Special Procedures

Where it is not possible to reduce the magnitude of an existing or potential hazard through design, or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Precautionary notations shall be standardized in accordance with the direction of the procuring activity.

5. Residual Hazards

Residual hazards for which safety or warning devices and special procedures cannot be developed or provided for counteracting the hazard shall be specifically identified to safety and program management. Continuation of effort to eliminate or reduce such hazards shall be accomplished



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throughout the program by maintaining awareness of new safety technology or devices being developed and their application to the residual hazards. Justification for the retention of residual hazards shall be documented."

The numbers 1 through 4 therefore represent the appropriate paragraphs of the HRPS satisfied by the particular requirement or guideline. No. 5, residual hazard, is not used here, since the term is reserved for the hazard or emergency as a whole (see item 15 below).

12. REQUIREMENT (R) OR GUIDELINE (G). This identifies by the letter R or G whether this is considered a requirement or guideline, as explained in item 8.
13. PREVENTIVE (P) OR REMEDIAL (R). This indicates whether this particular requirement or guideline contributes towards preventing (P) the stated hazard/emergency (item 4), or towards remedying (R) the situation after the hazard or emergency has occurred. This does not refer to whether or not the requirement or guideline prevents injury or damage following the occurrence of the hazard or emergency.
14. RGD REF. This reference indicates the volume and section of the Requirements and Guidelines documents (Volumes IV-V) of this report in which the individual requirements and guidelines are documented. Thus, V-I-3.2 indicates Volume V, part I, section 3.2. The inclusion of a requirement or guideline in a particular volume, say Volume IV (Earth Orbital Shuttle), must not be taken as a decision that the requirement or guideline must be implemented by that particular program (the Shuttle in this case) or charged to that program. It indicates that provision will physically be implemented on that vehicle (the Shuttle).
15. RESOLVED HAZARD. A hazard or emergency is considered to be resolved (for purposes of the study) if the recommended requirements and guidelines, when implemented, eliminate the possibility of injury or loss of personnel or damage to or loss of equipment from this particular hazard or emergency. A resolved hazard is indicated by an X in this box.
16. RESIDUAL HAZARD. A hazard or emergency is considered to be residual if injury or loss of personnel or damage to or loss of equipment is still possible from this hazard or emergency, even when the recommended requirements and guidelines have been implemented. A residual hazard is indicated by an X in this box. Each hazard/emergency is classified either as a resolved hazard or a residual hazard. A further disposition of the residual hazards into acceptable risks, supporting research and technology requirements and unresolved safety issues is contained in Volume II of this report.



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### 3.0 HAZARD/EMERGENCY ANALYSES

This section contains the completed hazard/emergency analyses. It is organized in five sections, 3.1 - 3.5, covering the analyses from the five individual tasks of the study. Each of these five sections is organized as follows:

- o A listing of requirements and guidelines which are common to more than one hazard/emergency analysis, identified by letters which are cross-referenced in the hazard/emergency analyses (see section 2.0, item 8).
- o The hazard/emergency analyses, in numerical order (see section 2.0, item 2).

REQUIREMENTS AND GUIDELINES APPEARING IN MORE THAN ONE HAZARD/EMERGENCY ANALYSIS.

1. HAZARDOUS PAYLOADS

- A. Upper stage vehicle pressures shall be limited while in or near the shuttle such that the factors of safety are at least equal to the shuttle tank factors of safety.
- B. Gaseous content of upper stage vehicle tanks shall be small enough so that rapid isentropic expansion into the shuttle cargo bay will not result in overpressure.
- C. Tanks shall be designed so that failure due to overpressure will not produce shrapnel.
- D. Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion.
- E. An external container of sufficient size and strength to contain all upper stage vehicle contents shall be provided.
- F. Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.
- G. Capability shall be provided for the shuttle crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bays open or closed.
- H. Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the shuttle.
- I. Cargo bay thermal insulation shall be designed as a fragmentation blanket.
- J. Shuttle hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary shuttle structure failure.
- K. Always-open cargo bay vents to space shall be provided on the shuttle which limit internal cargo bay pressures from upper stage vehicle leakage to the cargo bay allowable limits.





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- L. Capability shall be provided on the shuttle for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.
- M. Cargo bay doors shall be open at all times in earth orbit.
- N. All shuttle hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent shuttle abort.
- O. Vented gases from the shuttle cargo bay shall not be allowed to flow past the shuttle propellant tanks.
- P. Shuttle equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.
- Q. Liquid propellants of retrieved upper stage vehicles shall be dumped to space before initiation of the shuttle orbiter deorbit maneuver.
- R. Upper stage vehicle propellant tank pressures shall be reduced to the minimum operating value before retrieval into the orbiter cargo bay.
- S. Cargo bay pressure and selected wall temperatures shall be monitored.
- T. Capability shall be provided in the shuttle cargo bay for the detection of leakage of specific fluids on board the upper stage vehicles.
- U. Orbiter crew control of upper stage vehicle shall be provided until separation from the orbiter precludes possibility of recontact.
- V. Cargo bay surface materials which may be exposed to leaking corrosive fluids from payload shall be constructed or protected against corrosion.
- W. The upper stage vehicle shall be extended and released outside of the cargo bay such that upper stage vehicle rotation about its center of gravity in any direction upon release, will not impact any part of the orbiter.
- X. Procedures shall be available for extra-vehicular inspection and release or re-attachment of partially released upper stage vehicles in orbit.
- Y. Toxic fluid containers shall be located in unpressurized volumes of pressurized payloads, or shall be double contained with the capability of dumping the fluid to space or off-loading to another double container, and of venting the space between the two containers to space.



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- Z. Double contained toxic fluid containers shall be provided with means to detect leakage of the toxic fluid into the space between the containers, and with means to detect penetration of the outside container.
- a. Means shall be provided for detecting a toxic environment in pressurized orbit payloads containing toxic or potentially toxic fluids.
  - b. Emergency capability shall be provided to sustain personnel when in a manned payload, following detection of a toxic environment in the payload, until escape into the orbiter can be effected.
  - c. Special protective garments and equipment shall be provided for personnel working in a toxic environment or near potentially toxic payload elements.
  - d. Capability shall be provided to purge or dump to space a toxically contaminated atmosphere in a pressurized orbiter payload.
  - e. Capability shall be provided to purge or vent the orbiter airlock and tunnel to space following emergency egress of passengers from a toxic payload environment, or following IVA personnel entry for inspection and subsequent return to prevent the toxic environment from contaminating the orbiter crew and passenger compartment.
  - f. Means shall be provided to decontaminate personnel who have been exposed to a toxic environment in the payload which can be propagated to the orbiter before entering the orbiter crew and passenger compartments.
  - g. Instrumentation of payloads shall be provided to assist in isolating cause and source of fire.
  - h. Capability to release, eject, or extend the payload shall be provided so as to prevent damage to the orbiter at the expense of the payload.
  - i. Capability shall be provided for the orbiter crew to vent and dump flammable or hazardous payload fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.
  - j. Capability shall be provided to switch off all electrical loads to payload from the orbiter.
  - k. Thermal insulation shall be provided an orbiter cargo bay structure to minimize orbiter structure absorption of radiated heat from payload fire.
  - l. Thermal insulation shall be provided between orbiter cargo bay/payload attach points and other physical interfaces to minimize thermal conduction to orbiter structure.



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- m. Fire and heat resistant protection of orbiter to payload command and instrumentation interfaces shall be provided.
- n. Ignition sources in the orbiter bay, such as switches and relays, shall be sealed or otherwise contained so as to prevent ignition of flammable fluids.
- o. Hazardous fluids or materials shall be double contained during handling and transfer in pressurized areas. Capability shall be provided to verify the integrity of both containers before and after transfer.
- p. Capability shall be provided to vent the space between double containers for hazardous fluid handling to space and for dumping the fluid to space or off-loading to another container.
- q. Procedures shall be available for handling and transferring hazardous fluids or materials in a pressurized area from a singly penetrated double container to a storage container without releasing fluid or material to the spacecraft atmosphere.
- r. A lower pressure than the ambient atmosphere shall be maintained in containers of hazardous fluids or materials during handling and transfer in pressurized areas.
- s. A separate volume with an isolated environmental control shall be provided for testing and opening suspect hazardous fluid or material cargo containers. This volume shall have the capability to vent and dump the material to space and to be purged of hazardous fluid or material.
- t. Means shall be provided for detecting the presence of spilled hazardous fluids or materials while being handled or transferred between pressurized modules.
- u. Manual handling and transfer of hazardous fluids or materials shall be carried out by two or more personnel who shall have no other duties during this operation.
- v. During handling and transfer of hazardous fluids or materials, no other manned operations shall be planned along the transfer path.
- w. Mutually reactive fluids shall not be handled or transferred simultaneously.
- x. The pressures, temperatures, or other parameters which indicate the status of hazardous fluids or materials shall be verified before they are transported.
- y. Hand carried cargo shall be limited to 45 kg (100 lb) mass, provided the center of mass is within 35 cms (14 ins.) of the handhold. Cargo which exceeds these limits shall be transported with mechanical assist.



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- z. Cargo in which a rupture or leakage through the containers would result in uncontrolled motion of the cargo because of propulsive forces beyond a single man's capability to control or because toxicity requires immediate abandonment and evacuation of the area shall not be hand-carried.
- aa. Packaging of hand-carried cargo shall be provided with multiple hand holds, shall allow forward visibility by the controlling personnel, and shall be capable of surviving impact against a sharp object at 3 m/sec (10 ft/sec).
- bb. Provisions shall be made for rapidly securing hand-carried cargo to various structural points along the transfer path so as to prevent loss of control of the cargo in the event of an emergency.
- cc. Emergency procedures shall be available for handling, containing, and disposing of spilled hazardous fluids or materials so as to safeguard the personnel, orbiter and payload, in that order.
- dd. Cargo handling mechanisms shall allow for stoppage of the motion, reversal of the motion, or release of the cargo at any point along the transfer path.
- ee. The transfer of cargo with mechanical assist shall either be visually monitored by personnel who are free of other duties, or shall be provided with sensing devices which automatically stop the motion if the cargo interfaces with structure or equipment.
- ff. Personnel will not be located during cargo transfer in positions which can result in their entrapment if the cargo mechanism fails.
- gg. Emergency procedures shall be available for the release, handling and transportation of remotely controlled cargo in the event of failure of the handling mechanism, or of damage to the packaging of the cargo.
- hh. Cargo handling mechanisms shall be designed to withstand the propulsive forces that would result from a leaking or ruptured fluid cargo.

REQUIREMENTS AND GUIDELINES APPEARING IN MORE THAN ONE HAZARD/EMERGENCY ANALYSIS.

2. DOCKING

- A. The reaction jet control system shall provide redundancy to preclude "jet stuck off" conditions.
- B. The rate command and rate/attitude feedback loops of the rotational control system shall provide redundancy to preclude "open loop" failures.
- C. Inhibit capability shall be provided to control the "jet stuck on" condition.
- D. Space Station modules which are used in the free flying docking mode shall be provided with redundant means for communication, guidance, control, power, propulsion, and other functions critical to the docking.
- E. The operational status of systems on Space Station modules which are used in the free flying docking mode, including redundant systems, shall be verified before the module is separated from the orbiter or station.
- F. Emergency procedures shall be available for the orbiter to pursue and, if possible, dock to a Space Station module used in the free flying module docking mode which has lost control. These procedures shall allow personnel escape or rescue within their life support capability.
- G. Pressure suits and back packs shall be provided for all personnel on-board Space Station modules used in the free flying module docking mode. These suits shall be suitable for emergency EVA escape to a nearby Space Station or orbiter.
- H. An airlock capability which allows all on-board personnel to perform EVA emergency escape shall be provided on-board Space Station modules used in the free flying module docking mode. This may be provided by a separate 2-man airlock or may be an integral capability of the whole module.
- I. Emergency life support capability for all on-board personnel shall be provided on Space Station modules used in the free flying docking mode until emergency escape or rescue can be achieved.



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## REQUIREMENTS AND GUIDELINES APPEARING IN MORE THAN ONE HAZARD/EMERGENCY ANALYSIS.

### 3. ON-BOARD SURVIVABILITY

- A. Capability shall be provided to reduce the pressure in each compartment sufficiently, or increase it in the adjoining compartment(s) and to cut off air circulation, so that in an emergency the atmosphere in the affected compartment will not be propagated into adjoining compartments. This capability shall be controlled remotely from each compartment.
- B. Automatic venting capability shall be provided in each compartment so that in the event of a fire or release of gases within the compartment the pressure will not exceed the structural limits of the structure or the capability of seals to other compartments to exclude the contaminated atmosphere.
- C. Normally habitable compartments of more than  $25 \text{ m}^3$  ( $880 \text{ ft}^3$ ) in volume shall have two or more exits into areas which provide for personnel survival. These exits shall be at least 3 m. (10 ft) apart.
- D. Flammable, explosive or gas generating material shall be located so that the energy content which can be propagated at any one location shall not result in overpressurization of the compartment from heat and gas production.
- E. Flammable explosive or gas generating material within 3 m (10 ft) of the entrance to compartments with only one entry/egress path shall be limited so that the energy content, if released, will not result in damage or an environment which prevents shirtsleeve access through the entrance.
- F. Capability shall be provided for the emergency shirtsleeve survival of all on-board personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. A shirtsleeve accessible docking port shall be available. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all on-board personnel, including an available docking port.
- G. Emergency capability shall be provided on orbiter flights with a manned sortie module for the return to earth of all the passengers in the orbiter, without support from the sortie module.
- H. Emergency capability shall be provided on manned sortie modules for the return to earth of all the passengers in the sortie module, without life support from the orbiter.
- I. Orbiter equipment required for returning the orbiter to earth shall be capable of operation in a depressurized environment. The controls for this equipment shall be operable by crewmen in pressure suits.



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- J. A backup EVA egress/ingress hatch which can be used for contingency EVA shall be available. Capability for depressurization and repressurization of the connecting compartment/module shall be provided.
- K. On orbiter missions without attached manned sortie modules in which EVA is planned as part of the normal mission, pressure suits shall be carried for all on-board personnel.

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.001
DATE	7-27-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Explosion/rupture of a pressurized container in an upper stage vehicle inside or near orbiter.

## ASSUMPTIONS

1. Shuttle fluids are liquid hydrogen, liquid oxygen, gaseous helium, JP fuel, Aerozine -50, hydraulic fluid, water/glycol, nitrogen gas and nitrogen tetroxide.
2. Upper stage vehicles retain their current complement of pressurized containers.

(Continued on Page 2.)

## POTENTIAL EFFECTS

Damage to shuttle structure and equipment principally in cargo bay from: (1) Rupture of pressurized containers into fragments, (2) Initiation of a pressure wave producing shock, (3) Release of excessive fluid which increases cargo bay pressure beyond venting capability and increases heat leaks into shuttle propellant tanks.

## REQUIREMENTS &amp; GUIDELINES

- 1.A.Upper stage vehicle pressures shall be limited while in or near the shuttle such that the factors of safety are at least equal to the shuttle tank factors of safety.
- 2.B.Gaseous content of upper stage vehicle tanks shall be small enough so that rapid isentropic expansion into the shuttle cargo bay will not result in overpressure.
- 3.C.Tanks shall be designed so that failure due to overpressure will not produce shrapnel.
- 4.D.Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion.
- 5.E.An external container of sufficient size and strength to contain all upper stage vehicle contents shall be provided.

CODE	RGD REF.
X 1 G P	IV-4.2 V-II-3.1
X 1 G R	IV-4.2 V-II-3.1
X 1 G R	IV-4.2 V-II-3.1
X 2 R P	IV-4.2 V-II-3.2
- 2 G R	-

(Continued on Page 2.)

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD X



# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.1.001
DATE	7-27-71

## HAZARD/EMERGENCY

Explosion/rupture of a pressurized container in an upper stage vehicle inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## ASSUMPTIONS (cont)

2. (Continued)

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Helium Tanks	X	X	X		X	X
Nitrogen Tanks	X		X	X	X	
Nitrogen Tetroxide Tanks			X		X	
Aerozene -50 Tanks			X		X	
Hydrogen Peroxide Tanks		X		X		
Liquid Oxygen Tanks		X			X	X
Liquid Hydrogen Tanks		X			X	X
Monomethyl Hydrazine Tanks					X	
Water/Glycol Tanks					X	
Unsymmetrical Dimethyl Hydrazine	X					
Inhibited Red Fuming Nitric Acid	X					

## REQUIREMENTS & GUIDELINES (cont)

	<u>CODE</u>	<u>RGD REF</u>
6.F. Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.	X 3 R P	IV-3.3 V-II-3.3
7.G. Capability shall be provided for the shuttle crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 2 R P	IV-3.2 V-II-3.2
8.H. Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the shuttle.	X 4 R P	IV-3.4 V-II-3.4
9.I. Cargo bay thermal insulation shall be designed as a fragmentation blanket	- 1 G R	
10.J. Shuttle hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary shuttle structure failure.	X 1 R R	IV-3.1

(Continued on Page 3.)

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 3 OF 3

NO.	1.1.001
DATE	7-27-71

## HAZARD/EMERGENCY

Explosion/rupture inside of a pressurized container in an upper stage vehicle inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

	CODE
11.K. Always-open cargo bay vents to space shall be provided on the shuttle which limit internal cargo bay pressures from upper stage vehicle leakage to the cargo bay allowable limits.	X 1 R R IV-3.1
12.L. Capability shall be provided on the shuttle for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.	X 1 G R IV-3.1
13.M. Cargo bay doors shall be open at all times in earth orbit.	X 4 G R IV-3.4
14.N. All shuttle hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent shuttle abort.	X 1 R R IV-3.1
15.O. Vented gases from the shuttle cargo bay shall not be allowed to flow past the shuttle propellant tanks.	X 1 R R IV-3.1 V-II-4.1
16.P. Shuttle equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.	X 2 R R IV-3.2
17.Q. All upper stage vehicle liquid propellants shall be dumped to space before retrieval of the vehicle into the orbiter cargo bay.	X 4 R P IV-3.4 V-II-3.4
18.R. Upper stage vehicle propellant tank pressures shall be reduced to the minimum operating value before retrieval into the orbiter cargo bay.	X 4 R P IV-3.4 V-II-3.4

# HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.002
DATE	8-5-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Combination of mutually reactive upper stage vehicle fluids leading to explosion or fire inside or near orbiter.

## ASSUMPTIONS

1. Shuttle fluids are liquid hydrogen, liquid oxygen, gaseous helium, JP fuel, Aerozine -50, hydraulic fluid, water/glycol, nitrogen gas and nitrogen tetroxide.
2. Upper stage vehicles retain their current complement of propellants.

(Continued on Page 2.)

## POTENTIAL EFFECTS

Damage to shuttle structure and equipment principally in cargo bay from: 1) Initiation of a pressure wave producing shock; and 2) Heat input from radiation, circulation, and conduction of products of combustion.

## REQUIREMENTS & GUIDELINES

- 1.A Upper stage vehicle pressures shall be limited while in or near the shuttle such that the factors of safety are at least equal to the shuttle tank factors of safety.
- 2.B.Gaseous content of upper stage vehicle tanks shall be small enough so that rapid isentropic expansion into the shuttle cargo bay will not result in overpressure.
- 3.D.Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion.
- 4.E.An external container of sufficient size and strength to contain all upper stage vehicle contents shall be provided.
- 5.F.Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.

(Continued on Page 2.)

CODE RGD REF.

X 1 G P IV-4.2  
V-II-3.1

X 1 G R IV-4.2  
V-II-3.1

X 2 R P IV-4.2  
V-II-3.2

- 2 G R -

X 3 R P IV-3.3  
V-II-3.3

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD X

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 3

NO.	1.1.002
DATE	8-5-71

## HAZARD/EMERGENCY

Combination of mutually reactive upper stage vehicle fluids in explosion or fire inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

ASSUMPTIONS (cont)

## 2. (Continued)

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Nitrogen Tetroxide			X		X	
Aerozene -50			X		X	
Hydrogen Peroxide		X		X		
Liquid Oxygen		X			X	X
Liquid Hydrogen		X			X	X
Monomethyl Hydrazine					X	
Water/Glycol					X	
Unsymmetrical Dimethyl Hydrazine	X					
Inhibited Red Fuming Nitric Acid	X					

REQUIREMENTS & GUIDELINES (cont)

	<u>CODE</u>	<u>RGD REF</u>
6.G.Capability shall be provided for the shuttle crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 2 R P	IV-3.2 V-II-3.2
7.H.Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the shuttle.	X 4 R P	IV-3.4 V-II-3.4
8.I.Cargo bay thermal insulation shall be designed as a fragmentation blanket.	- 1 G R	-
9.J.Shuttle hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary shuttle structure failure.	X 1 R R	IV-3.1
10.K.Always-open cargo bay vents to space shall be provided on the shuttle which limit internal cargo bay pressures from upper stage vehicle leakage to the cargo bay allowable limits.	X 1 R R	IV-3.1

(Continued on Page 3.)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 3 OF 3

NO.	1.1.002
DATE	8-5-71

## HAZARD/EMERGENCY

Combination of mutually reactive upper stage vehicle fluids in explosion or fire inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

- |  |         |                    |
|--|---------|--------------------|
| 11.L. Capability shall be provided on the shuttle for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents. | X 1 G R | IV-3.1             |
| 12.M. Cargo bay doors shall be open at all times in earth orbit.   | X 4 G R | IV-3.4             |
| 13.N. All shuttle hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent shuttle abort.  | X 1 R R | IV-3.1             |
| 14.O. Vented gases from the shuttle cargo bay shall not be allowed to flow past the shuttle propellant tanks.  | X 1 R R | IV-3.1<br>V-II-4.1 |
| 15.P. Shuttle equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.   | X 2 R R | IV-3.2             |
| 16.S. Cargo bay pressure and selected wall temperatures shall be monitored.  | X 3 G R | IV-3.3             |
| 17.T. Capability shall be provided in the shuttle cargo bay for the detection of leakage of specific fluids on board the upper stage vehicles.   | - 1 R F | -                  |
| 18.Q. Liquid propellants of retrieved upper stage vehicles shall be dumped to space before initiation of the shuttle orbiter deorbit maneuver.   | X 4 R P | IV-3.4<br>V-II-3.4 |
| 19.R. Upper stage vehicle propellant tank pressures shall be reduced to the minimum operating value before retrieval into the orbiter cargo bay.   | X 4 R P | IV-3.4<br>V-II-3.4 |

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.003
DATE	8-5-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inadvertent detonation of explosive charge on upper stage vehicle inside or near orbiter.

## ASSUMPTIONS

1. Upper stage vehicles retain their current complement of pyrotechnics:

(Continued on Page 2.)

## POTENTIAL EFFECTS

Damage to the shuttle structure and equipment principally in the cargo bay from (a) detonation of the explosive charge and shattering of the housing sending 1) shrapnel and 2) pressure waves into the surroundings, and (b) from separation of the upper stage vehicle in the cargo bay.

## REQUIREMENTS &amp; GUIDELINES

1. Housings of explosive charges shall be designed to prevent damage to equipment required for shuttle abort in the event of inadvertent detonation.
2. All powder filled volumes shall be designed to allow verification of content by neutron ray inspection before flight.
3. Destruct charges shall not be incorporated in upper stage vehicles when launched in the shuttle.
- 4.I. Cargo bay thermal insulation shall be designed as a fragmentation blanket
- 5.J. Shuttle hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary shuttle structure failure.

(Continued on Page 2.)

CODE RGD REF.

X 1 R P IV-4.2  
V-II-3.1

- 1 G P -

X 1 R P IV-4.2  
V-II-3.1

- 1 G R -

X 1 R R IV-3.1

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.003
DATE	8-5-71

## HAZARD/EMERGENCY

Inadvertent detonation of explosive charge on upper stage vehicle inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

### ASSUMPTIONS (cont)

#### 1. (Continued)

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>CSM</u>	<u>OOS/Tug</u>
Connections Between Modules - Cutters.					X	
Helium Valves.	X		X			
Solid Propellant Igniters.				X		
Turbine Start Solid Pro- pellant Charges.	X					
Explosive Bolts - Payload Separation.	X	X	X	X	X	X
Linear Shaped Charge - Panel Separation.	X	X			X	
Destruct Shaped Charges.	X	X	X	X	X	X
External Extensions - Antennae.					X	

### REQUIREMENTS & GUIDELINES (cont)

- 6.N. All shuttle hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent shuttle abort.
7. The amount of charge in each housing shall be below 0.1 lb TNT equivalent.
8. Interlocks, redundancy, grounding and isolation devices shall be provided on explosive charges so that no single detectable failure or combination of undetectable failures shall result in premature detonation.

CODE	RGD REF
X 1 R R	IV-3.1
- 1 G P	-
X 2 R P	IV-3.2

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.004
DATE	8-5-71

## HAZARD/EMERGENCY

SOURCE II-2.1,2

Rapid decomposition of monopropellants located in or leaking from the upper stage vehicle while inside or near orbiter.

## ASSUMPTIONS

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Aerozene -50			X		X	
Monomethyl Hydrazine					X	
Hydrogen Peroxide		X		X		
Solid Propellant	X			X		
Unsymmetrical Dimethyl Hydrazine	X					

## POTENTIAL EFFECTS

Damage to shuttle structure and equipment, principally in the cargo bay from: 1) shrapnel, 2) pressure wave and 3) heat.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Upper stage vehicle monopropellant temperatures and pressures shall be monitored.	X 3 R R	IV-3.3 V-II-3.3
2. Crew procedures for monopropellant dump shall be provided in case of rapid rise in pressure or temperature.	X 4 R R	IV-3.4 V-II-3.4
3. Cleanliness of the monopropellant and all materials in normal contact with the fluid shall be controlled so that spontaneous decomposition in normal and emergency environments is not possible.	X 4 R P	V-II-3.4
4. Catalyst materials shall not be placed in the cargo bay where they may come into contact with monopropellants from a leaking or ruptured line or tank.	- 1 G P	-
5.B. Gaseous content of upper stage vehicle tanks shall be small enough so that rapid isentropic expansion into the shuttle cargo bay will not result in overpressure.	X 1 G R	IV-4.2 V-II-3.1
6.D. Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion.	X 2 R P	IV-4.2 V-II-3.2
	X X X X	

(Continued on Page 2.)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)

NO. OF HRPS (1, 2, 3, 4)

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)



# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.1.004
DATE	8-5-71

## HAZARD/EMERGENCY

Rapid decomposition of monopropellants located in or leaking from the upper stage vehicle while inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF
7.C.Tanks shall be designed so that failure due to overpressure will not produce shrapnel.	X 1 G R	IV-4.2 V-II-3.1
8.F.Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.	X 3 R P	IV-3.3 V-II-3.3
9.G.Capability shall be provided for the shuttle crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 2 R P	IV-3.2 V-II-3.2
10.I.Cargo bay thermal insulation shall be designed as a fragmentation blanket.	- 1 G R	-
11.J.Shuttle hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary shuttle structure failure.	X 1 R R	IV-3.1
12.K.Always-open cargo bay vents to space shall be provided on the shuttle which limit internal cargo bay pressures from upper stage vehicle leakage to the cargo bay allowable limits.	X 1 R R	IV-3.1
13.L. Capability shall be provided on the shuttle for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.	X 1 G R	IV-3.1
14.M.Cargo bay doors shall be open at all times in earth orbit.	X 4 G R	IV-3.4
15.N.All shuttle hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent shuttle abort.	X 1 R R	IV-3.1 V-II-4.1
16.O.Vented gases from the shuttle cargo bay shall not be allowed to flow past the shuttle propellant tanks.	X 1 R R	IV-3.1 V-II-4.1

(Continued on Page 3.)

HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 3 OF 3

NO.	1.1.004
DATE	8-5-71

HAZARD/EMERGENCY

Rapid decomposition of monopropellants located in or leaking from the upper stage vehicle while inside or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

CODE RGD REF

17.P.Shuttle equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.

X 2 R RIV-3.2

18.Q.Liquid propellants of retrieved upper stage vehicles shall be dumped to space before initiation of the shuttle orbiter deorbit maneuver.

X 4 R PIV-3.4  
V-II-3.4

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.005
DATE	8-9-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Uncontrolled combustion in active upper stage vehicle reaction control engines while near the orbiter.

## ASSUMPTIONS

1. RCS propellants remain the same on upper stage vehicles.

	<u>Transtage</u>	<u>SM</u>	<u>OOS/Tug</u>
Aerozene -50 + Nitrogen Tetroxide	X		
Monomethyl Hydrazine + Nitrogen Tetroxide		X	
Hydrogen Gas + Oxygen Gas			X

(Continued on Page 2.)

## POTENTIAL EFFECTS

Damage to shuttle structure and equipment, principally in the cargo bay from explosion of the engine sending, 1) shrapnel, 2) pressure waves, and 3) heat into shuttle equipment, and from uncontrolled upper stage vehicle motion.

## REQUIREMENTS &amp; GUIDELINES

1. Cold gas jets or control moment gyros for upper stage vehicles shall be used when operating near the orbiter.
2. The upper stage vehicle shall use jets on the opposite side from the orbiter for maneuvers near the orbiter.
3. Capability shall be provided to detect combustion instability during firing.
4. U Orbiter crew control of upper stage vehicle shall be provided until separation from the orbiter precludes possibility of recontact.
5. Orbiter orientation shall point the longitudinal axis toward the separated upper stage vehicle until a safe separation distance has been achieved.

CODE	RGD REF.
- 1 G P	--
- 4 G P	--
- 3 G R	--
X 4 R P	IV-3.4 V-II-3.4
X 4 R R	IV-3.4 V-II-4.1

X X X X

RECOMMENDED (X) OR NOT (-)

NO. OF HRPS (1, 2, 3, 4)

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	X
RESIDUAL HAZARD	

HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 2 OF 2

NO.	1.1.005
DATE	8-9-71

HAZARD/EMERGENCY

Uncontrolled combustion in active upper stage vehicle reaction control engines while near the orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

ASSUMPTIONS (cont)

2. The upper stage vehicle reaction control system is activated immediately upon separation from the orbiter.
3. Main engine burn will occur on the upper stage vehicle at a large, safe, separation distance from the orbiter.

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.006
DATE	8-9-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Leakage of corrosive fluids from upper stage vehicle tanks while inside the orbiter.

## ASSUMPTIONS

1. Upper stage vehicles retain current complement of corrosive fluids:

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner</u>	<u>SM</u>	<u>OOS/Tug</u>
Nitrogen Tetroxide			X		X	
Hydrogen Peroxide		X		X		
Liquid Oxygen		X			X	X
Inhibited Red Fuming Nitric Acid	X					

## POTENTIAL EFFECTS

Damage to orbiter structure and equipment principally in the cargo bay from corrosion of orbiter components as a result of leakage of corrosive fluids.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1.A Upper stage vehicle pressures shall be limited while in or near the orbiter such that the factors of safety are at least equal to the orbiter tank factors of safety.	X 1 G P	IV-4.2 V-II-3.1
2.B Gaseous content of upper stage vehicle tanks shall be small enough so that rapid isentropic expansion into the orbiter cargo bay will not result in overpressure.	X 1 G R	IV-4.2 V-II-3.1
3.E An external container of sufficient size and strength to contain all upper stage vehicle contents shall be provided.	- 2 G R	--
4.F Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.	X 3 R P	IV-3.3 V-II-3.3
5.G Capability shall be provided for the orbiter crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 2 R P	IV-3.2 V-II-3.2

(Continued on Page 2.)

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.1.006
DATE	8-9-71

## HAZARD/EMERGENCY

Leakage of corrosive fluids from upper stage vehicle tanks while inside the orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
6.H Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the orbiter.	X 4 R P	IV-3.4 V-II-3.4
7.D Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion	X 2 R P	IV-4.2 V-II-3.2
8.K Always-open cargo bay vents to space shall be provided on the shuttle which limit internal cargo bay pressures from upper stage vehicle leakage to the cargo bay allowable limits.	X 1 R R	IV-3.1
9.L Capability shall be provided on the orbiter for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.	X 1 G R	IV-3.1
10.M Cargo bay doors shall be open at all times in earth orbit.	X 4 G R	IV-3.4
11.N All orbiter hardware contained in and near the shuttle cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent orbiter abort.	X 1 R R	IV-3.1
12.O Vented gases from the shuttle cargo bay shall not be allowed to flow past the orbiter propellant tanks.	X 1 R R	IV-3.1 V-II-4.1
13.P Orbiter equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.	X 2 R R	IV-3.2
14.S Cargo bay pressure and selected wall temperatures shall be monitored.	X 3 G R	IV-3.3
15.T Capability shall be provided in the orbiter cargo bay for the detection of leakage of specific fluids on board the upper stage vehicles.	- 1 R P	--
16.V Cargo bay surface materials which may be exposed to leaking corrosive fluids from payload shall be constructed or protected against corrosion.	X 1 G R	IV-3.1

(Continued on Page 3.)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 3 OF 3

NO.	1.1.006
DATE	8-9-71

## HAZARD/EMERGENCY

Leakage of corrosive fluids from upper stage vehicle tanks while inside the orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
17.J Orbiter hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary orbiter structure failure.	X 1 R R	IV-3.1
18.Q Liquid propellants of retrieved upper stage vehicles shall be dumped to space before initiation of the shuttle orbiter deorbit maneuver.	4 R P	IV-3.4 V-II-3.4
19.R Upper stage vehicle propellant tank pressures shall be reduced to the minimum operating value before retrieval into the orbiter cargo bay.	X 4 R P	IV-3.4 V-II-3.4

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.007
DATE	8-10-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inadvertent start of an upper stage vehicle main or reaction control rocket engine while inside orbiter cargo bay.

## ASSUMPTIONS

1. Upper stage vehicle retains the current complement of rocket engines.

Type of Engine	Number of Engines					
	Agena	Centaur	Transtage	Burner II	SM	OOS/Tug
Main Engine	1	2	2	1	1	1-4
RCS Engine		8	12	4	16	20

2. Inadvertent firing of an upper stage vehicle main propulsion engine while in the cargo bay will be catastrophic to the orbiter.

## POTENTIAL EFFECTS

Damage to orbiter equipment in the cargo bay from 1) over-heating by direct heating from the exhaust plume, 2) over-pressure from the products of combustion, 3) changing the insulating properties of the space between shuttle tanks, and 4) impulse, rotation and translation, leading to structural and equipment damage.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Propellant shut-off valves upstream from all start valves shall be provided so that inadvertent main valve opening would not start engines on upper stage vehicles while in or near the orbiter.	X 1 R P	IV-4.2 V-II-3.1
2. The design of the upper stage vehicle control system shall only allow supply of electrical energy to the start valves of the rocket engines following positive action by the orbiter crew during upper stage vehicle count-down in orbit.	X 1 R P	IV-4.2 V-II-3.1
3.G Capability shall be provided for the orbiter crew to vent and dump upper-stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 2 R P	IV-3.2 V-II-32.
4.H Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the orbiter.	X 4 R P	IV-3.2 V-II-3.2
5. Always-open cargo bay vents to space shall be provided on the orbiter which limit internal cargo bay pressures from the combustion products of a single upper stage vehicle reaction control rocket engine to the cargo bay allowable limits.	X 1 R R	IV-3.1
	X X X X	

(Continued on Page 2.)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)



# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.007
DATE	8-10-71

## HAZARD/EMERGENCY

Inadvertent start of an upper stage vehicle main or reaction control rocket engine while inside orbiter cargo bay.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)	CODE	RGD REF.
6.L Capability shall be provided on the orbiter for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.	X 1 G R	IV-3.1
7.M Cargo bay doors shall be open at all times in earth orbit.	X 4 G R	IV-3.4
8.N All orbiter hardware contained in and near the orbiter cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent orbiter abort.	X 1 R R	IV-3.1
9.O Vented gases from the orbiter cargo bay shall not be allowed to flow past the orbiter propellant tanks.	X 1 R R	IV-3.1 V-II-4.1
10.P Orbiter equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.	X 2 R R	IV-3.2
11. Insulation patches shall be provided on the cargo bay walls opposite all payload reaction control engines which will protect the walls from the combustion products.	- 2 G R	--
12.U Orbiter crew control of upper stage vehicle shall be provided until separation from the orbiter precludes possibility of recontact.	X 4 R R	IV-3.4 V-II-4.1
13.Q Liquid propellants of retrieved upper stage vehicles shall be dumped to space before initiation of the shuttle orbiter deorbit maneuver.	X 4 R P	IV-3.4 V-II-3.4

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.008
DATE	8-12-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inadvertent separation of an upper stage vehicle attach point while in the orbiter.

## ASSUMPTIONS

The upper stage vehicles are supported in the orbiter cargo bay at a discrete number of attachment points.

## POTENTIAL EFFECTS

1. Damage to the orbiter structure and equipment, particularly in the cargo bay, from collision with loose upper stage vehicle equipment or payload.
2. Inability to re-enter and land orbiter if payload remains loose in cargo bay.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. The factors of safety for the upper stage vehicle and orbiter attachment point shall be at least equal to the normal orbiter structure factors of safety.	X 1 G P	IV-3.1 V-II-3.1
2. The upper stage vehicle shall be supported in the orbiter so that failure of any one structural support member will not jeopardize support of the upper stage vehicle during return to earth.	X 1 R P	IV-3.1 V-II-3.1
3. The design of the upper stage vehicle control system shall only allow supply of electrical energy to the separation mechanism following positive action by the orbiter crew during upper stage vehicle count-down in orbit.	X 1 R P	IV-4.2 V-II-3.1
4. The internal surface of the cargo bay shall be coated with a shock absorbent blanket.	- 1 G R	--
5. A restraint system shall be provided for the upper stage vehicles in the orbiter cargo bay which prevents contact of the vehicle with orbiter structure or equipment in the event of partial or total release of the attachment points.	X 2 R P	IV-3.2 V-II-3.2

Continued on Page 2.)

X X X X

SOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.008
DATE	8-12-71

## HAZARD/EMERGENCY

Inadvertent separation of an upper stage vehicle attach point while in the orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
6. Procedures shall be available to apply unidirectional translational or rotational acceleration to the orbiter in the event of a partial or total release of the payload in the cargo bay until loose parts and the payload have settled sufficiently to allow further corrective action.	X 4 R R	IV-3.4
7. Procedures shall be available for backing off the orbiter from an upper stage vehicle inadvertently separated in the orbiter cargo bay without contact of the upper stage vehicle with orbiter structure or equipment while in orbit.	X 4 R R	IV-3.4
8. Procedures shall be available for extra-vehicular inspection and release or re-attachment of partially released upper stage vehicles in orbit.	X 4 R R	IV-3.4
9. Means shall be provided to indicate to the orbiter crew that a retrieved upper stage vehicle is positively secured at all attach points prior to deorbit and reentry.	X 3 R P	IV-3.3

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.009
DATE	8-12-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Loss of attitude/translation control of upper stage vehicle upon release from orbiter.

## ASSUMPTIONS

- Upper stage vehicle has attitude hold and/or translation capabilities.

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Translation - Main Engine	X(1)*	X(1)	X(1)	X(1)	X(1)	X(1)
- RCS			X(1)	X(2)	X(6)	X(6)
- Auxiliary	X	X(1)				
Attitude Hold - RCS Couples					X	X
- Off-Center	X	X	X			
* ( ) Number of directions	(Continued on Page 2.)					

## POTENTIAL EFFECTS

- Damage to shuttle structure and equipment on cargo bay doors and near external skin from collision with the out-of-control upper stage vehicle or payload.
- Catastrophic damage to upper stage vehicle leading to explosion and orbiter structural failure.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Attitude control couples in all six rotational modes shall be provided on upper stage vehicles.	X 1 G P	V-II-3.1
2. The planned attitudes of the upper stage vehicle during release and separation from the orbiter shall be such that the attitude control engines at no time accelerate the vehicle towards the orbiter.	X 4 G R	IV-3.4 V-II-3.4
3. All attitude control engines and electronics shall be redundant on upper stage vehicles.	X 1 R P	V-II-3.1
4. The cargo bay doors shall be opened sufficiently so that they cannot be struck by the released upper stage vehicle under any rotation about its center of gravity.	- 1 G R	-
5. The upper stage vehicle shall be extended and released outside of the cargo bay such that upper stage vehicle rotation about its center of gravity in any direction upon release, will not impact any part of the orbiter.	X 1 R R	IV-3.1 V-II-4.1
6. All venting of the upper stage vehicles while near the orbiter shall be non-propulsive or shall translate the vehicle away from the orbiter.	X 1 R P	IV-4.2 V-II-3.1

(Continued on Page 2.)

X X X X

RECOMMENDED (X) OR NOT (-)  
 NO. OF MRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
 RESIDUAL HAZARD X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.1.009
DATE	8-12-71

## HAZARD/EMERGENCY

Loss of attitude/translation control of upper stage vehicle upon release from orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## ASSUMPTIONS (cont)

2. Source of stability remains the same as current vehicles.

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Gyro Reference	X	X		X		X
Accelerometers	X	X				
Computer/Flight Control	X	X		X		X

3. The capability of the orbiter to accelerate during upper stage deployment is less than that of the upper stage vehicle.

## REQUIREMENTS & GUIDELINES (cont)

	<u>CODE</u>	<u>RDG REF.</u>
7. No torques shall be imparted to the upper stage vehicle by the separation mechanism.	X 1 G P	IV-3.1 V-II-3.1
8. Orbiter shall be moved away from upper stage vehicle immediately on release.	X 4 R R	IV-3.4
9. Upper stage vehicle attitude and translation shall be monitored by the orbiter crew immediately following release.	X 4 R R	IV-3.4
10. Upper stage vehicle attitude shall be controlled by command of the orbiter crew immediately following release.	X 4 R R	IV-3.4 V-II-3.4
11. Internal attitude control signal of the upper stage vehicle shall be monitored for accuracy by the orbiter crew before release.	X 4 R	IV-3.4 V-II-3.4
12. Upper stage vehicle shall be switched from command control to internal attitude control after orbiter has been sufficiently moved that no attitude change could result in collision.	X 4 R P	IV-3.4 V-II-3.4
13. Upper stage vehicle shall be switched from command control by the orbiter crew to internal translation control when sufficient time is available for the orbiter crew to execute evasive maneuvers following any main propulsion or guidance failure.	X 4 R R	IV-3.4 V-II-3.4
14. Upper orbiter surfaces capable of being struck by the released upper stage vehicle during any attitude maneuver shall be strengthened to prevent damage (to orbiter components required for de-orbit, re-entry, and landing) for the condition of the worst possible attitude acceleration.	- 1 G R	-

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 3 OF 3

NO.	1.1.009
DATE	8-12-71

## HAZARD/EMERGENCY

Loss of attitude/translation control of upper stage vehicle upon release from orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

### REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
15. Coverings around the upper stage vehicle tanks shall be provided to prevent any leak from becoming directional and imparting unwanted attitude or translation motion.	- 2 G P	-
16.J. Orbiter hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary orbiter structure failure.	X 1 R R	IV-3.1
17. All orbiter hardware contained in and near the orbiter cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent orbiter abort.	X 1 R R	IV-3.1
18. The trajectories of the orbiter and the upper stage vehicle shall be continually compared following release, and a means for shutting down the upper stage vehicle shall be provided if a collision appears imminent.	X 4 R R	IV-3.4 V-II-3.4

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.010
DATE	8-13-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Hangup of upper stage vehicle during release from orbiter.

## ASSUMPTIONS

- Attachment methods will be the same as currently required for boost vehicles.

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Explosive Bolts				X		
Linear Shaped Charge	X	X	X		X	
Not Defined						X

## POTENTIAL EFFECTS

- Damage to orbiter structure and equipment from random motion of the upper stage vehicle in an extended position.
- Inability of the orbiter to re-enter because of the open cargo bay doors.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Redundancy shall be provided in the means for separating the upper stage vehicle. No single failure shall result in unprogrammed motion of the upper stage vehicle.	X 1 R P	IV-3.1 V-II-3.1
2. The upper stage vehicle shall be extended and released outside of the cargo bay such that upper stage vehicle rotation about any one attachment point in any direction upon release, will not impact any part of the orbiter.	X 1 R R	IV-3.1 V-II-4.1
3. Special orbiter attitude and translation motions shall be planned to assist release of any single residual connection with the upper stage vehicle.	X 4 G R	IV-3.4 V-II-4.1
4. Orbiter to upper stage vehicle connections shall be designed for emergency manual release by orbiter crew member in extravehicular activity.	X 1 R R	IV-3.1 V-II-3.1
5. Emergency release of the extension mechanism shall be possible in order to save the orbiter at the expense of the upper stage vehicle.	X 1 R R	IV-3.1

(Continued on Page 2.)

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 2 OF 2

NO.	1.1.010
DATE	8-13-71

HAZARD/EMERGENCY

Hangup of upper stage vehicle during release from orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

6.X.Procedures shall be available for extra-vehicular inspection and release or re-attachment of partially released upper stage vehicles in orbit.

7. Procedures shall be available to apply unidirectional translational or rotational acceleration to the orbiter in the event of a partial release of the upper stage vehicle in the extended position to prevent random motion.

CODE

RGD REF.

X 4 R R IV-3.4  
V-II-3.4

- 4 G R -



## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.011
DATE	8-16-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Rupture of common bulkhead tanks in upper stage vehicle while in or near orbiter.

## ASSUMPTIONS

1. Some upper stage vehicles will use common bulkhead tanks, e.g., Centaur.

## POTENTIAL EFFECTS

A propellant combination which could burn immediately (for hypergolics) or could become an explosive mixture (for cryogenics) capable of being detonated by a small energy input. Orbiter damage would be catastrophic in either case.

## REQUIREMENTS &amp; GUIDELINES

CODE RGD REF.

- |   |         |                    |
|---|---------|--------------------|
| 1. For upper stage vehicles with propulsion tanks using common bulkheads, differential pressure between the two tanks, common bulkhead strain, or other indications of potential failure, shall be monitored by the Orbiter crew.   | X 3 R P | IV-3.3<br>V-II-3.3 |
| 2. For upper stage vehicles with propulsion systems using common bulkheads, venting of the high pressure tank shall be automatic when a high differential pressure or strain is measured between the two tanks.   | - 2 G P | -                  |
| 3. Capability shall be provided for the orbiter crew to selectively pressurize or vent each tank of an upper stage vehicle using a common bulkhead. This capability shall be available with the orbiter cargo bay doors open or closed.   | X 2 R P | IV-3.2<br>V-II-3.2 |
| 4.H. Pressurizing gas on upper stage vehicles shall be turned off until immediately prior to release of the vehicle from the orbiter.   | X 4 R P | IV-3.4<br>V-II-3.4 |
| 5.D. Relief capability shall be provided for the upper stage vehicle tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion. | X 2 R P | IV-4.2<br>V-II-3.2 |
|   | X X X X |                    |

(Continued on Page 2.)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 2 OF 2

NO.	1.1.011
DATE	8-16-71

HAZARD/EMERGENCY

Rupture of common bulkhead tanks in upper stage vehicle while in or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

6.G.Capability shall be provided for the orbiter crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.

<u>CODE</u>	<u>RGD REF.</u>
X 2 R P	IV-3.2 V-II-3.2

7. For upper stage vehicles with propulsion systems using common bulkheads, the design of the propulsion system shall only allow pressurization of both tanks to occur simultaneously, so as not to exceed the allowable differential pressure.

X 1 R P	V-II-3.1
---------	----------

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	
	SORTIE	X
	STATION	

NO.	1.1.012
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Loss of pressurization in pressure stabilized upper stage vehicle structure while in or near orbiter.

## ASSUMPTIONS

1. Some upper stage vehicles will use a pressure stabilized structure, e.g., the Centaur.
2. It is desirable to return a collapsed upper stage vehicle to earth rather than abandon it in orbit.

## POTENTIAL EFFECTS

1. Reparable or permanent damage to the upper stage vehicle.
2. Damage to orbiter equipment and structure from collapse of the upper stage vehicle.

## REQUIREMENTS &amp; GUIDELINES

CODE RGD REF.

- |   |         |                    |
|---|---------|--------------------|
| 1. A backup means shall be provided for the orbiter crew to vent or pressurize upper stage vehicles with a pressure stabilized structure.   | X 1 R P | IV-3.1<br>V-II-3.1 |
| 2. The support structure of a pressure stabilized upper stage vehicle in the shuttle shall allow shuttle de-orbit, re-entry and landing following loss of pressurization in the upper stage vehicle while in the orbiter cargo bay in orbit.                    | X 1 G R | IV-3.1<br>V-II-3.1 |
| 3. F. Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.   | X 3 R P | IV-3.3<br>V-II-3.3 |
| 4. J. Orbiter hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of upper stage vehicle explosions which would not cause primary orbiter structure failure.                                   | X 1 R R | IV-3.1             |
| 5. N. All orbiter hardware contained in and near the orbiter cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent orbiter abort. | X 1 R R | IV-3.1             |

(Continued on Page 2.)

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	X
RESIDUAL HAZARD	

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.012
DATE	8-17-71

## HAZARD/EMERGENCY

Loss of pressurization in pressure stabilized upper stage vehicle structure while in or near orbiter.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

### REQUIREMENTS & GUIDELINES (cont)

- 6.X. Procedures shall be available for extravehicular inspection and release or re-attachment of depressurized upper stage vehicles in orbit.
7. Sufficient upper stage vehicle support shall be provided by the orbiter to prevent collapse during any transport phase, regardless of pressure.
8. The pressure stabilized structure shall be capable of being filled and stabilized with foam while in orbit following jettison or use of internal fluids.

#### CODE

#### RGD REF.

X 4 R R IV-3.4  
V-II-3.4

- 2 G R -

- 2 G R -

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.013
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inability to dump propellants or pressurants in retrieved upper stage vehicle.

## ASSUMPTIONS

1. Upper stage vehicles retain their current complement of pressurized containers.

(Continued on Page 2.)

## POTENTIAL EFFECTS

Damage to orbiter structure and equipment from release of residual propellants or pressurants into the cargo bay.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Dumping of propellants and pressurants from a retrieved upper stage vehicle shall be accomplished before initiation of the shuttle orbiter deorbit maneuver.	X 4 R P	IV-3.4 V-II-3.4
2. Dumping of propellants and pressurants from a retrieved upper stage vehicle shall be controlled by the orbiter crew.	X 4 R P	IV-3.4 V-II-3.4
3. A backup means of dumping propellants and pressurants from a retrieved upper stage vehicle shall be available.	X 1 R P	IV-3.1 V-II-3.1
4. The orbiter auxiliary propulsion system shall provide an upper stage vehicle propellant settling maneuver before firing of the orbit maneuvering system, de-orbit engines.	- 4 G R	-
5. An upper stage vehicle in which propellant and pressurants have not been dumped shall not be returned into the orbiter cargo bay.	X 4 R R	IV-3.4 V-II-3.4

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	X
RESIDUAL HAZARD	

TBD-88-3138

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.013
DATE	8-17-71

## HAZARD/EMERGENCY

Inability to dump propellants or pressurants in retrieved upper stage vehicle.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

## ASSUMPTIONS (cont)

2. (Continued)

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Helium Tanks	X	X	X		X	X
Nitrogen Tanks	X		X	X	X	
Nitrogen Tetroxide Tanks			X		X	
Aerozene -50 Tanks			X		X	
Hydrogen Peroxide Tanks		X		X		
Liquid Oxygen Tanks		X			X	X
Liquid Hydrogen Tanks		X			X	X
Monomethyl Hydrazine Tanks					X	
Water/Glycol Tanks					X	
Unsymmetrical Dimethyl Hydrazine	X					
Inhibited Red Fuming Nitric Acid	X					

# HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.014
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inability to dump upper stage vehicle propellants or pressurants during orbiter abort.

## ASSUMPTIONS

1. Upper stage vehicles retain their current complement of pressurized containers.

(Continued on Page 2.)

## POTENTIAL EFFECTS

1. Inability to return upper stage vehicle to earth.
2. Damage to orbiter structure and equipment from overloading during de-orbit, re-entry and landing with fully loaded launch payload.

## REQUIREMENTS & GUIDELINES

1. The orbiter shall have the capability to de-orbit, re-enter and land with a fully loaded upper stage vehicle as payload.
2. Sufficient propellants for orbiter de-orbit and landing with on-board, fully loaded upper stage vehicle shall be retained on the until main engine ignition of the upper stage vehicle.
- 3.G.Capability shall be provided for the orbiter crew to vent and dump upper stage vehicle pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.

CODE RGD REF.

X 1 R R IV-3.1

X 4 R R IV-3.4

X 2 R P IV-3.2  
V-II-3.2

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.014
DATE	8-17-71

## HAZARD/EMERGENCY

Inability to dump upper stage vehicle propellants or pressurants during orbiter abort.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## ASSUMPTIONS (cont)

(Continued)

	<u>Agena</u>	<u>Centaur</u>	<u>Transtage</u>	<u>Burner II</u>	<u>SM</u>	<u>OOS/Tug</u>
Helium Tanks	X	X	X		X	X
Nitrogen Tanks	X		X	X	X	
Nitrogen Tetroxide Tanks			X		X	
Aerozene -50 Tanks			X		X	
Hydrogen Peroxide Tanks		X		X		
Liquid Oxygen Tanks		X			X	X
Liquid Hydrogen Tanks		X			X	X
Monomethyl Hydrazine Tanks					X	
Water/Glycol Tanks					X	
Unsymmetrical Dimethyl Hydrazine	X					

Inhibited Red Fuming Nitric Acid X

2. The shuttle is designed for a lower return payload weight than it can deliver to orbit.

3. The shuttle and its payload has achieved orbit.



## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	

NO.	1.1.015
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.1.2

Inability to close cargo bay doors after retrieval of upper stage vehicle because of interference with upper stage vehicle.

## ASSUMPTIONS

Orbiter cargo bay doors must be closed before re-entry.

## POTENTIAL EFFECTS

1. Inability of orbiter to re-enter.
2. Damage to orbiter cargo bay doors or cargo bay.
3. Damage or loss of upper stage vehicle.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Capability shall be provided for visual inspection of an orbiter payload before initiating retrieval and loading into the orbiter cargo bay.	X 4 R P	IV-3.4 V-I-4.1 V-II-4.1
2. Positive indication shall be provided to the orbiter crew that a retrieved payload has been properly secured in the cargo bay before closing the cargo bay doors.	X 3 R P	IV-3.3 V-I-4.1 V-II-4.1
3. Automatic means shall be provided for detecting interferences by the payload with the closing of the cargo bay doors and stopping the motion before damage results to the doors or the door mechanism.	X 2 R R	IV-3.2
4. Means shall be provided for re-opening the cargo bay doors from any partially closed position.	X 1 R R	IV-3.1
5. Capability shall be provided for visual inspection of an orbiter payload in the orbiter cargo bay with the cargo bay doors open.	X 2 R P	IV-3.2
6. Procedures shall be available for extravehicular or remote inspection, extension, and release or re-positioning of improperly stowed upper stage vehicles in orbit.	X 4 R R	IV-3.4 V-II-4.1
	X X X X	

(Continued on Page 2.)

RESOLVED HAZARD  
RESIDUAL HAZARD X

RECOMMENDED (X) OR NOT (-)  
NO. OF NRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.1.015
DATE	8-17-71

## HAZARD/EMERGENCY

Inability to close cargo bay doors after retrieval of upper stage vehicle because of interference with upper stage vehicle.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
7. Capability for extra-vehicular activity shall be provided to disconnect, sever, or otherwise free cables, deployed mechanisms or other upper stage vehicle protruberances which could interfere with retrieval and stowage in the orbiter.	X 2 R P	IV-3.2
8. Positive indication shall be provided to the orbiter crew that the cargo bay doors have closed and latched before initiating de-orbit.	X 3 R R	IV-3.3
9. The capability shall be provided on upper stage vehicles for remote emergency jettisoning of deployable equipment to allow retrieval and stowage in the orbiter cargo bay.	X 1 G P	IV-4.2 V-II-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.2.001
DATE	8-10-71

## HAZARD/EMERGENCY

SOURCE II-2.2.6

Exposure of the orbiter crew or passengers to a toxic environment released from a vessel in the payload containing a toxic fluid.

## ASSUMPTIONS

1. The payload is capable of being pressurized for manned occupancy.
2. An airlock interface exists between the orbiter and the payload.
3. Toxic or potentially toxic fluids are carried in the orbiter payload.

## POTENTIAL EFFECTS

1. Injured or disabled orbiter crewmen or passengers due to toxic payload fluids gaining access to the orbiter environmental control and life support system.
2. Injured or disabled passengers in pressurized payload due to toxic payload environment.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1.Y Toxic fluid containers shall be located in unpressurized volumes of pressurized payloads, or shall be double contained with the capability of dumping the fluid to space or off-loading to another double container, and of venting the space between the two containers to space.	X 1 R P	V-I-3.1 V-III-3.1
2.Z Double contained toxic fluid containers shall be provided with means to detect leakage of the toxic fluid into the space between the containers, and with means to detect penetration of the outside container.	X 3 R P	V-I-3.3 V-III-3.3
3.a Means shall be provided for detecting a toxic environment in pressurized orbiter payloads containing toxic or potentially toxic fluids.	X 3 R P	V-I-3.3 V-III-3.3
4.b Emergency capability shall be provided to sustain personnel when in a manned payload, following detection of a toxic environment in the payload, until escape into the orbiter can be effected.	X 2 R R	V-I-3.2 V-III-3.2
5.c Special protective garments and equipment shall be provided for personnel working in a toxic environment or near potentially toxic payload elements.	X 2 R P	V-I-3.2 V-3.7
	X X X X	

(Continued on Page 2.)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
NO. OF MRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.2.001
DATE	8-10-71

## HAZARD/EMERGENCY

Exposure of the orbiter crew or passengers to a toxic environment released from a vessel in the payload containing a toxic fluid.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD. REF.
6.d Capability shall be provided to purge or dump to space a toxically contaminated atmosphere in a pressurized orbiter payload.	X 1 R R	V-I-3.1
7.e Capability shall be provided to purge or vent the orbiter airlock and tunnel to space following emergency egress of passengers from a toxic payload environment, or following IVA personnel entry for inspection and subsequent return to prevent the toxic environment from contaminating the orbiter crew and passenger compartment.	X 1 R P	IV-3.1
8.f Means shall be provided to decontaminate personnel who have been exposed to a toxic environment in the payload which can be propagated to the orbiter before entering the orbiter crew and passenger compartments.	X 2 R R	IV-3.2
9. Means shall be provided for determining the presence of an unacceptable toxic environment in the orbiter as a result of toxic contamination in a payload.	X 3 R P	IV-3.3
10. Emergency capability shall be provided in the orbiter to purge the orbiter pressurized volumes of a toxic environment that may result from toxic contamination of a payload, and to sustain orbiter personnel during the purging operation.	X 1 R P	IV-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.2.002
DATE	8-27-71

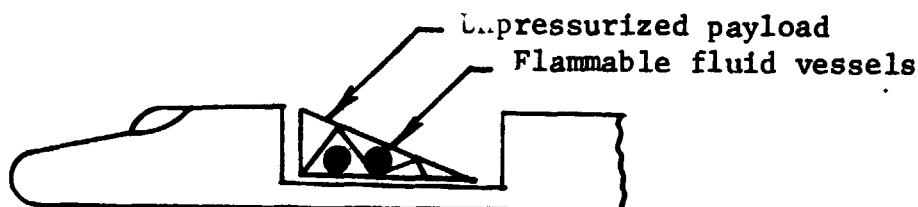
## HAZARD/EMERGENCY

SOURCE II-2.2.6

A fire in the cargo bay resulting from release and ignition of a flammable fluid in an unpressurized payload.

## ASSUMPTIONS

1. The payload is unpressurized and contains vessels of flammable fluids.



2. Fire can be sustained in the unpressurized cargo bay long enough to cause damage.

## POTENTIAL EFFECTS

1. Damage to payload.
2. Damage to orbiter structure and equipment in the cargo bay, possible preventing de-orbit, re-entry, and landing.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. The orbiter cargo bay shall be vented to space or the orbiter cargo bay doors shall be opened at all times while on-orbit to preclude buildup of pressures in the cargo bay capable of supporting combustion.	X 1 R P	IV-3.1
2. Fire detection and location capability, such as distributed thermocouples, infrared detectors, or remote control TV, shall be provided in the cargo bay for use while the cargo bay doors are closed.	X 3 R R	IV-3.3
3. Procedures shall be available for immediately initiating opening of the cargo bay doors if a fire is detected in the cargo bay while the doors are shut.	X 4 R R	IV-3.4
4.g Instrumentation of payloads shall be provided to assist in isolating cause and source of fire.	- 3 R R	—
5.h Capability to release, eject, or extend the payload shall be provided so as to prevent damage to the orbiter at the expense of the payload.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
6.i Capability shall be provided for the orbiter crew to vent and dump flammable or hazardous payload fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
	X X X X	

(Continued on Page 2.)

RESOLVED HAZARD ☐  
RESIDUAL HAZARD ☒

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.2.002
DATE	8-27-71

## HAZARD/EMERGENCY

A fire in the cargo bay resulting from release and ignition of a flammable fluid in an unpressurized payload.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD. REF.
7.j Capability shall be provided to switch off all electrical loads to payload from the orbiter.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1
8.k Thermal insulation shall be provided on orbiter cargo bay structure to minimize orbiter structure absorption of radiated heat from payload fire.	- 1 R P	--
9.1 Thermal insulation shall be provided between orbiter cargo bay/payload attach points and other physical interfaces to minimize thermal conduction to orbiter structure.	- 1 R P	--
10m Fire and heat resistant protection of orbiter to payload command and instrumentation interfaces shall be provided.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1
11. A warning indication shall be provided to the orbiter crew of a spilled flammable fluid or a fire hazard environment in the orbiter cargo bay.	- 1 G P	--
12. Capability shall be provided to deluge monopropellant and chemical decomposition fires with cold inert gas to reduce or eliminate chemical activity if venting to space does not eliminate fire.	- 1 R P	--
13.n Ignition sources in the orbiter bay, such as switches and relays, shall be sealed or otherwise contained so as to prevent ignition of flammable fluids.	X 1 R P	IV-3.1 V-I-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.2.003
DATE	8-27-71

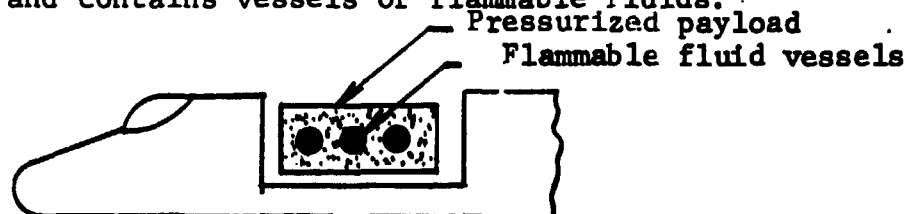
## HAZARD/EMERGENCY

SOURCE III-2.2.6 ,

A fire in a pressurized payload in the cargo bay resulting from release and ignition of a flammable fluid.

## ASSUMPTIONS

1. The payload is pressurized, but not necessarily manned at all times, and contains vessels of flammable fluids.



2. Ignition sources will exist during manned operations in the payload.
3. An airlock interface exists between the orbiter and the payload.

## POTENTIAL EFFECTS

1. Damage to payload.
2. Rupture/explosion of the payload, leading to damage to orbiter.
3. Injury or loss of personnel in the payload module.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1.Y Flammable fluid containers shall be located in unpressurized volumes of pressurized payloads, or shall be double contained with the capability of dumping the fluid to space or off-loading to another double container, and of venting the space between the two containers to space.	X 1 R P	V-I-3.1 V-III-3.1
2.Z Double contained flammable fluid containers shall be provided with means to detect leakage of the flammable fluid into the space between the containers, and with means to detect penetration of the outside container.	X 3 R P	V-I-3.3 V-III-3.3
3.a Means shall be provided for detecting a flammable or oxygen enriched environment in pressurized shuttle payloads containing flammable fluids.	X 3 R P	V-I-3.3 V-III-3.3
4. Means shall be provided for detecting the presence of a fire in pressurized shuttle payloads.	X 3 R R	IV-3.3

(Continued on Page 2.)

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.2.003
DATE	8-27-71

## HAZARD/EMERGENCY

A fire in a pressurized payload in the cargo bay resulting from release and ignition of a flammable fluid.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD. REF.
5. Manually and remotely controlled means shall be provided in pressurized orbiter payloads for controlling and extinguishing fires.	X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
6. Emergency life support shall be provided for all personnel in manned orbiter payloads sufficient to allow them time to control a fire and/or escape to the orbiter.	X 2 R R	V-I-3.2 V-III-3.2
7. Capability shall be provided to isolate orbiter environmental control system from payload to prevent toxic fumes from entering the orbiter.	X 1 R R	IV-3.1 V-I-4.1 V-III-4.1
8. Capability shall be provided to automatically shut off forced air circulation in a pressurized orbiter payload upon detection of a fire.	X 1 R R	V-I-3.1 V-III-3.1
9. Capability shall be provided to relieve atmospheric pressure from orbiter payload so as to prevent pressurization beyond the payload structural limits. This capability shall be automatic when the payload is not manned, and under control of the occupants when manned. The maximum dump rate shall not exceed the venting capability of the orbiter cargo bay with the cargo bay doors closed.	X 2 R R	IV-4.1 IV-4.3 V-I-3.2 V-III-3.2
10.i Capability shall be provided for the orbiter crew to vent and dump flammable or hazardous payload fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
11.d Capability shall be provided to purge or dump to space a toxically contaminated atmosphere in a pressurized orbiter payload.	X 1 R R	V-I-3.1 V-III-3.1
12.j Capability shall be provided to switch off all electrical loads to payload from orbiter.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1

(Continued on Page 3.)



## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 3 OF 3

NO.	1.2.003
DATE	8-27-71

## HAZARD/EMERGENCY

A fire in a pressurized payload in the cargo bay resulting from release and ignition of a flammable fluid.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

13.n Ignition sources in orbiter pressurized payloads, such as switches and relays, shall be sealed or otherwise contained so as to prevent ignition of flammable fluids.	X 1 R P	IV-3.1 V-I-3.1
14.h Capability to release, eject, or extend the payload shall be provided so as to prevent damage to the orbiter at the expense of the payload.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1
15.g Instrumentation of payloads shall be provided to assist in isolating cause and source of fire.	- 3 R P	—
16.k Thermal insulation shall be provided on orbiter cargo bay structure to minimize orbiter structure absorption of radiated heat from payload fire.	- 1 R P	—
17.1 Thermal insulation shall be provided between orbiter cargo bay/payload attach points and other physical interfaces to minimize thermal conduction to orbiter structure.	- 1 R P	—
18.m Fire and heat resistant protection of orbiter to payload command and instrumentation interfaces shall be provided.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1
19. Materials used in pressurized payloads shall be subject to the same flammability control procedures as those used within the orbiter pressurized volumes.	X 1 R R	V-I-3.1 V-III-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.2.004
DATE	8-27-71

## HAZARD/EMERGENCY

SOURCE II-2.2.6

A corrosive environment in the orbiter cargo bay resulting from leakage or rupture of a payload vessel containing a corrosive fluid.

## ASSUMPTIONS

1. An airlock interface exists between the orbiter and the payload.
2. Corrosive fluids are carried in the orbiter payload.

## POTENTIAL EFFECTS

1. Damage to payload.
2. Damage to orbiter structure and equipment in the cargo bay, possible preventing de-orbit, re-entry, and landing.

## REQUIREMENTS &amp; GUIDELINES

- 1.Y Corrosive fluid containers shall be located in unpressurized volumes of pressurized payloads, or shall be double contained with the capability of dumping the fluid to space or off-loading to another double container, and of venting the space between the two containers to space.
- 2.Z Double contained corrosive fluid containers shall be provided with means to detect leakage of the corrosive fluid into the space between the containers, and with means to detect penetration of the outside container.
- 3.d Capability shall be provided to purge or dump to space a corrosive atmosphere in a pressurized orbiter payload.
- 4.V Cargo bay surface materials which may be exposed to leaking corrosive fluids from payload shall be constructed or protected against corrosion.
5. Instrumentation shall be provided to detect leakage of corrosive fluids from container or piping.

CODE	RGD REF.
X 1 R P	V-I-3.1 V-III-3.1
X 3 R P	V-I-3.3 V-III-3.3
X 1 R R	V-I-3.1 V-III-3.1
X 1 G R	IV-3.1
- 1 R R	---
X X X X	

(Continued on Page 2.)

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD

RESIDUAL HAZARD

X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.2.004
DATE	8-27-71

## HAZARD/EMERGENCY

A corrosive environment in the orbiter cargo bay resulting from leakage or rupture of a payload vessel containing a corrosive fluid.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD. REF.
6. Access for visual inspection by intravehicular activity or remotely by instrumentation shall be provided to all primary structure inside the cargo bay & equipment in the cargo bay required for return to earth.	X 1 G R	IV-3.1 V-I-4.1 V-III-4.1
7. Access for visual inspection by intravehicular activity or remotely by instrumentation shall be provided to all primary structure of pressurized payloads while in the orbiter cargo bay.	X 1 G R	IV-4.1 IV-4.3 V-I-3.1 V-III-3.1
8. Means shall be provided for the local application of radiant or other type of heat remotely or by personnel in IVA or EVA activity to evaporate accumulations of frozen fluids from critical areas.	X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
9.0 Vented gases from the orbiter cargo bay shall not be allowed to flow past the orbiter propellant tanks.	X 1 R R	IV-3.1
10.P Orbiter equipment and structure exposed to vented gases from the cargo bay shall be protected against the effects of corrosion and be capable of inspection on the ground.	X 2 R R	IV-3.2
11.V Cargo bay surface materials which may be exposed to leaking corrosive fluids from payload shall be constructed or protected against corrosion.	X 1 G R	IV-3.1
12.e Capability shall be provided to purge or vent the orbiter airlock and tunnel space following emergency egress of passengers from a corrosive payload environment, or following IVA personnel entry for inspection and subsequent return to prevent the corrosive environment from contaminating the orbiter crew and passenger compartment.	X 1 R P	IV-3.1
13.f Means shall be provided to decontaminate personnel who have been exposed to a corrosive environment in the payload which can be propagated to the orbiter before entering the orbiter crew and passenger compartments.	X 2 R R	IV-3.2

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.2.005
DATE	8-27-71

## HAZARD/EMERGENCY

SOURCE II-2.2.6

An explosion in the orbiter cargo bay of a potentially explosive payload vessel.

## ASSUMPTIONS

The orbiter payload includes potentially explosive fluid tanks in (a) the unpressurized cargo bay, or (b) in a pressurized or unpressurized module which cannot contain the explosion.

## POTENTIAL EFFECTS

Damage to orbiter structure and equipment principally in cargo bay from: (1) Rupture of pressurized containers into fragments, (2) Initiation of a pressure wave producing shock, (3) Release of excessive fluid which increases cargo bay pressure beyond venting capability and increases heat leaks into orbiter propellant tanks.

## REQUIREMENTS &amp; GUIDELINES

1. The factors of safety of pressure vessels while in or near the orbiter shall be at least equal to the orbiter tank factors of safety.
2. Gaseous content of pressurized tanks shall be small enough so that rapid isentropic expansion into the orbiter cargo bay will not result in overpressure.
3. C Tanks shall be designed so that failure due to overpressure will not produce shrapnel.
4. Relief capability shall be provided for pressurized tanks which automatically limit maximum pressure. Venting shall be to space or to a tank at lower pressure, and shall be arranged so that mutually reactive fluids cannot mix and result in a fire or explosion.
5. F Capability shall be provided to detect potential tank failures by measurement of fluid pressures, temperatures, tank strains, or other means.

(Continued on Page 2.)

CODE	RGD REF.
X 1 G P	IV-4.1 IV-4.3 V-I-3.1 V-III-3.1
X 1 R R	V-I-3.1 V-III-3.1
X 1 G R	V-I-3.1 V-III-3.1
X 2 R P	IV-4.1 IV-4.3 V-I-3.2 V-III-3.2
X 3 R P	IV-4.1 IV-4.3 V-I-3.3 V-III-3.3
X X X X	

RESOLVED HAZARD	
RESIDUAL HAZARD	x

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.2.005
DATE	8-27-71

## HAZARD/EMERGENCY

An explosion in the orbiter cargo bay of a potentially explosive payload vessel.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE
6.1 Capability shall be provided for the orbiter crew to vent and dump pressurized or hazardous fluids to space within the time constraints imposed by an abort situation. This capability shall be available with the cargo bay doors open or closed.	X 1 R P IV-3.1 V-I-3.1 V-III-3.1
7.1 Cargo bay thermal insulation shall be designed as a fragmentation blanket.	- 1 G R --
8. Orbiter hardware required for abort shall be located remotely from the cargo bay, or protected against the potential effects of payload explosions which would not cause primary shuttle structure failure.	X 1 R R IV-3.1
9. Always-open cargo bay vents to space shall be provided on the orbiter which limit internal cargo bay pressures from leakage to the cargo bay allowable limits.	X 1 R R IV-3.1
10.1 Relief valves shall be provided on the orbiter for automatic cargo bay venting when the always-open vents are inadequate, in order to increase the allowable flow from inside to outside and to protect against re-entry ingestion through always-open vents.	- 1 G R --
11.1 Cargo bay doors shall be open at all times in earth orbit.	X 4 G R IV-3.4
12.1 All orbiter hardware contained in and near the orbiter cargo bay shall be capable of being functionally isolated from those components necessary for de-orbit, re-entry and landing so that an accident in the cargo bay shall not prevent orbiter abort.	X 1 R R IV-3.1
13. Pressurized tanks shall be located or protected by shrapnel proof barriers so that explosion of one will not propagate to others.	X 1 R R V-I-3.1 V-III-3.1
14. Pressurized tanks shall be located or provided with shrapnel proof barriers so that orbiter crew and passenger compartments and equipment required for orbiter return to earth will be protected in the event of a tank explosion.	X 1 R R IV-4.1 IV-4.3 V-I-3.1 V-III-3.1

(Continued on Page 3.)

HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 2 OF 3

NO.	1.2.005
DATE	8-27-71

HAZARD/EMERGENCY

An explosion in the orbiter cargo bay of a potentially explosive payload vessel.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

	<u>CODE</u>	<u>RGD REF</u>
15. Blowout plugs shall be provided for pressure release from payload to space.	- 2 R R	---
16. Blowout panels shall be provided in orbiter cargo bay which could be re-sealable after use.	- 2 R R	---

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	
	SORTIE	X
	STATION	X

NO.	1.3.001
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.3.4

Spillage or leakage of hazardous fluid or material during manual transfer in pressurized modules.

## ASSUMPTIONS

Hazardous fluids or materials are not carried in or transported through the orbiter crew and passenger compartments or through the airlock.

## POTENTIAL EFFECTS

1. Injury or loss of personnel.
2. Damage to spacecraft equipment.

## REQUIREMENTS &amp; GUIDELINES

- 1.o Hazardous fluids or materials shall be double contained during handling and transfer in pressurized areas. Capability shall be provided to verify the integrity of both containers before and after transfer.
- 2.p Capability shall be provided to vent the space between double containers for hazardous fluid handling to space and for dumping the fluid to space or off-loading to another container.
- 3.g Procedures shall be available for handling and transferring hazardous fluids or materials in a pressurized area from a singly penetrated double container to a storage container without releasing fluid or material to the spacecraft atmosphere.
- 4.r A lower pressure than the ambient atmosphere shall be maintained in containers of hazardous fluids or materials during handling and transfer in pressurized areas.

(Continued on Page 2.)

CODE RGD REF.

X 2 R P V-I-3.2  
V-III-3.2X 2 R P V-I-3.2  
V-III-3.2X 4 R P V-I-3.4  
V-III-3.4

- 1 G P —

X X X X

RECOMMENDED (X) OR NOT ( )  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.3.001
DATE	8-17-71

## HAZARD/EMERGENCY

Spillage or leakage of hazardous fluid or material during manual transfer in pressurized modules.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF
5.s A separate volume with an isolated environmental control shall be provided for testing and opening suspect hazardous fluid or material cargo containers. This volume shall have the capability to vent and dump the material to space and to be purged of hazardous fluid or material.	- 1 G P	—
6.t Means shall be provided for detecting the presence of spilled hazardous fluids or materials while being handled or transferred between pressurized modules.	X 3 G R	V-I-3.3 V-III-3.3
7.b Emergency capability shall be provided to sustain personnel when in a manned payload, following detection of a toxic environment in the payload, until escape into the orbiter can be effected.	X 2 R R	V-I-3.2 V-III-3.2
8.c Special protective garments and equipment shall be provided for personnel working in a toxic environment or near potentially toxic payload elements.	X 2 R R	V-I-3.2 V-III-3.2
9.d Capability shall be provided to purge or dump to space a toxically contaminated atmosphere in a pressurized orbiter payload.	X 1 R R	V-I-3.1 V-III-3.1
10.u Manual handling and transfer of hazardous fluids or materials shall be carried out by two or more personnel who shall have no other duties during this operation.	X 4 R P	V-I-3.4 V-III-3.4
11.v During handling and transfer of hazardous fluids or materials, no other manned operations shall be planned along the transfer path.	X 4 R P	V-I-3.4 V-III-3.4
12.w Mutually reactive fluids shall not be handled or transferred simultaneously.	X 4 R R	V-I-3.4 V-III-3.4
13.x The pressures, temperatures, or other parameters which indicate the status of hazardous fluids or materials shall be verified before they are transported.	X 4 R P	V-I-3.4 V-III-3.4

(Continued on Page 3.)



# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 3 OF 3

NO.	1.3.001
DATE	8-17-71

## HAZARD/EMERGENCY

Spillage or leakage of hazardous fluid or material during manual transfer in pressurized modules.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF.
14.y Hand carried cargo shall be limited to 45 kg (100 lb) mass, provided the center of mass is within 35 cms (14 ins.) of the handhold. Cargo which exceeds these limits shall be transported with mechanical assist.	X 4 R P	V-I-3.4 V-III-3.4
15.z Cargo in which a rupture or leakage through the containers would result in uncontrolled motion of the cargo because of propulsive forces beyond a single man's capability to control or because toxicity requires immediate abandonment and evacuation of the area shall not be hand-carried.	X 4 G R	V-I-3.4 V-III-3.4
16.aaPackaging of hand-carried cargo shall be provided with multiple hand holds, shall allow forward visibility by the controlling personnel, and shall be capable of surviving impact against a sharp object at 3 m/sec (10 ft/sec).	X 2 R P	V-I-3.2 V-III-3.2
17.bbProvisions shall be made for rapidly securing hand-carried cargo to various structural points along the transfer path so as to prevent loss of control of the cargo in the event of an emergency.	X 2 R P	V-I-3.2 V-III-3.2
18.cc Emergency procedures shall be available for handling, containing, and disposing of spilled hazardous fluids or materials so as to safeguard the personnel, orbiter and payload, in that order.	X4RR	V-I-3.4 V-III-3.4

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	
	SORTIE	X
	STATION	X

NO.	1.3.002
DATE	8-17-71

## HAZARD/EMERGENCY

SOURCE II-2.3.4

Spillage or leakage of hazardous fluids or materials during mechanically assisted or remote transfer of pressurized modules.

## ASSUMPTIONS

1. Mechanical assist may range from a simple guide-rail for transportation by hand, to fully automatic mechanism or fluid transfer system remotely and with no physical manned participation.
2. Hazardous fluids or materials are not carried in or transported through the orbiter crew and passenger compartments, or through the airlock.

## POTENTIAL EFFECTS

1. Injury or loss of personnel.
2. Damage to spacecraft equipment.

## REQUIREMENTS &amp; GUIDELINES

- 1.o Hazardous fluids or materials shall be double contained during handling and transfer in pressurized areas. Capability shall be provided to verify the integrity of both containers before and after transfer.
- 2.p Capability shall be provided to vent the space between double containers for hazardous fluid handling to space and for dumping the fluid to space or off-loading to another container.
- 3.q Procedures shall be available for handling and transferring hazardous fluids or materials in a pressurized area from a singly penetrated double container to a storage container without releasing fluid or material to the spacecraft atmosphere.
- 4.r A lower pressure than the ambient atmosphere shall be maintained in containers of hazardous fluids or materials during handling and transfer in pressurized areas.

## CODE

## RGD REF.

X 2 R P V-I-3.2  
V-III-3.2X 2 R P V-I-3.2  
V-III-3.2X 4 R P V-I-3.4  
V-III-3.4

- 1 G P —

(Continued on Page 2.)

RECOMMENDED (X) OR NOT ( )  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD

RESIDUAL HAZARD

X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.3.002
DATE	8-17-71

## HAZARD/EMERGENCY

Spillage or leakage of hazardous fluids or materials during mechanically assisted or remote transfer in pressurized modules.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF
5.8 A separate volume with an isolated environmental control shall be provided for testing and opening suspect hazardous fluid or material cargo containers. This volume shall have the capability to vent and dump the material to space and to be purged of hazardous fluid or material.	1 G P	—
6.t Means shall be provided for detecting the presence of spilled hazardous fluids or materials while being handled or transferred between pressurized modules.	X 3 G R	V-I-3.3 V-III-3.3
7.b Emergency capability shall be provided to sustain personnel when in a manned payload, following detection of a toxic environment in the payload, until escape into the orbiter can be effected.	X 1 R R	V-I-3.2 V-III-3.2
8. c Special protective garments and equipment shall be provided for personnel working in a toxic environment or near potentially toxic payload elements.	X 2 R R	V-I-3.2 V-III-3.2
9.d Capability shall be provided to purge or dump to space a toxically contaminated atmosphere in a pressurized orbiter payload.	X 1 R R	V-I-3.1 V-III-3.1
10.v During handling and transfer of hazardous fluids or materials, no other manned operations shall be planned along the transfer path.	X 4 R P	V-I-3.4 V-III-3.4
11.w Mutually reactive fluids shall not be handled or transferred simultaneously.	X 4 R R	V-I-3.4 V-III-3.4
12.x The pressures, temperatures, or other parameters which indicate the status of hazardous fluids or materials shall be verified before they are transported.	X 4 R P	V-I-3.4 V-III-3.4
13. Transfer lines for hazardous fluids shall be located outside of pressurized vessels or shall be double walled with the capability of venting the space between the two containers to space.	X 1 R R	V-I-3.4 V-III-3.4

(Continued on Page 3.)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 3 OF 3

NO.	1.3.002
DATE	8-17-71

## HAZARD/EMERGENCY

Spillage or leakage of hazardous fluids or materials during mechanically assisted or remote transfer in pressurized modules.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF
14. Plumbing connections for hazardous fluid transfer in pressurized areas shall be double contained with the capability of venting the space between the two containers to space.	X 1 R R	V-I-3.1 V-III-3.1
15. Transfer lines in pressurized areas, including double walled lines, shall be purged after the transfer of hazardous fluids and before breaking plumbing connections.	X 4 R P	V-I-3.4 V-III-3.4
16. Cargo beyond the limits allowed for hand transfer shall be transferred on guide rails or other mechanisms which positively constrain the angular and linear motion of the cargo except in the direction of motion.	X 1 R P	V-I-3.1 V-III-3.1
17.ddCargo handling mechanisms shall allow for stoppage of the motion, reversal of the motion, or release of the cargo at any point along the transfer path.	X 1 R P	V-I-3.1 V-III-3.1
18.eeThe transfer of cargo with mechanical assist shall either be visually monitored by personnel who are free of other duties, or shall be provided with sensing devices which automatically stop the motion if the cargo interfaces with structure or equipment.	X 4 R P	V-I-3.4 V-III-3.4
19.ffPersonnel will not be located during cargo transfer in positions which can result in their entrapment if the cargo transfer mechanism fails.	X 4 R R	V-I-3.4 V-III-3.4
20.ggEmergency procedures shall be available for the release, handling and transportation of remotely controlled cargo in the event of failure of the handling mechanism, or of damage to the packaging of the cargo.	X 4 G P	V-I-3.4 V-III-3.4
21.hhCargo handling mechanisms shall be designed to withstand the propulsive forces that would result from a leaking or ruptured fluid cargo.	X 1 R R	V-I-3.1 V-III-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	
	SORTIE	X
	STATION	X

NO.	1.3.003
DATE	8-20-71

## HAZARD/EMERGENCY

SOURCE II-2.3.4

Spillage or leakage of hazardous fluid or material during remote transfer in unpressurized area.

## ASSUMPTIONS

1. Mechanisms for cargo transfer may range from being fully under manned control, to fully preprogrammed and automated.
2. Hazardous fluids or materials are not carried in, or transported through, the orbiter crew and passenger compartments or through the airlock.

## POTENTIAL EFFECTS

Damage to spacecraft structure and equipment.

## REQUIREMENTS &amp; GUIDELINES

1. Corrosive fluids or materials shall be double contained during handling and transfer in unpressurized areas. Capability shall be provided to verify the integrity of both containers before and after transfer.
2. w Mutually reactive fluids shall not be handled or transferred simultaneously.
3. x The pressures, temperatures, or other parameters which indicate the status of hazardous fluids or materials shall be verified before they are transported.
4. Transfer lines in unpressurized areas shall be purged after the transfer of hazardous fluids.
5. dd Cargo handling mechanisms shall allow for stoppage of the motion, reversal of the motion, or release of the cargo at any point along the transfer path.

CODE	RGD REF.
X 2 R P	V-I-3.2 V-III-3.2
X 4 R R	V-I-3.4 V-III-3.4
X 4 R P	V-I-3.4 V-III-3.4
X 4 R P	V-I-3.4 V-III-3.4
X 1 R P	V-I-3.1 V-III-3.1

(Continued on Page 2.)

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT ( ) \_\_\_\_\_  
NO. OF HRPS (1, 2, 3, 4) \_\_\_\_\_  
REQUIREMENT (R) OR GUIDELINE (G) \_\_\_\_\_  
PREVENTIVE (P) OR REMEDIAL (R) \_\_\_\_\_

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.3.003
DATE	8-20-71

## HAZARD/EMERGENCY

Spillage or leakage of hazardous fluid or material during remote transfer in unpressurized area.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (cont)

	<u>CODE</u>	<u>RGD REF</u>
6.ee The transfer of cargo with mechanical assist shall either be visually monitored by personnel who are free of other duties, or shall be provided with sensing devices which automatically stop the motion if the cargo interfaces with structure or equipment.	X 4 R P	V-I-3.4 V-III-3.4
7.gg Emergency procedures shall be available for the release, handling and transportation of remotely controlled cargo in the event of failure of the handling mechanism, or of damage to the packaging of the cargo.	X 4 G P	V-I-3.4 V-III-3.4
8.hh Cargo handling mechanisms shall be designed to withstand the propulsive forces that would result from a leaking or ruptured fluid cargo.	X 1 R R	V-I-3.1 V-III-3.1
9. Separate lines shall be used for the transfer of fuel and oxidizer.	X 1 R R	V-I-3.1 V-III-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 3

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.3.004
DATE	8-20-71

## HAZARD/EMERGENCY

SOURCE II-2.3.4

Failure of transfer mechanism and/or loss of control of cargo during transfer in pressurized or unpressurized areas.

## ASSUMPTIONS

Possible failure modes include:

- Cargo moving loose in zero g.
- Cargo moving attached to runaway cargo transfer mechanism.
- Cargo jammed.

## POTENTIAL EFFECTS

- Injury to personnel.
- Damage to spacecraft structure and equipment.

## REQUIREMENTS &amp; GUIDELINES

- Cargo of more than 45 kg (100 lb) mass, or hazardous cargo shall be tethered at all times during handling and transfer in pressurized areas either to the spacecraft structure or to the transfer mechanism so as to limit the possible travel of the cargo following a failure of the primary cargo attach mechanism.
- Automatic and/or crew controlled emergency means shall be provided for shutting off power and arresting the motion of cargo transfer mechanisms.
- Cargo shall be packaged during transfer so as to have no exposed sharp edges or corners.
- Crew controlled cargo transfer velocity shall be limited so that the cargo can at all times be stopped within the visible range.
- Emergency procedures shall be available for releasing cargo which has become jammed in hatches or other restricted areas without causing damage to the spacecraft structure or equipment.

## CODE

## RGD REF.

X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
X 2 R R	IV-3.2 V-I-3.1 V-III-3.2
X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
X 1 R P	V-I-3.1 V-III-3.1
X 4 R R	IV-3.4 V-I-3.4 V-III-3.4

(Continued on Page 2.)

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)

NO. OF HRPS (1, 2, 3, 4)

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 3

NO.	1.3.004
DATE	8-20-71

## HAZARD/EMERGENCY

Failure of transfer mechanism and/or loss of control of cargo during transfer in pressurized or unpressurized areas.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## REQUIREMENTS & GUIDELINES (cont)

	CODE	RGD REF
6.u Manual handling and transfer of hazardous fluids or materials shall be carried out by two or more personnel who shall have no other duties during this operation.	X 4 R P	IV-3.4 V-I-3.4 V-III-3.4
7.y Hand carried cargo shall be limited to 45 kg (100 lb) mass, provided the center of mass is within 35 cms (14 ins.) of the handhold. Cargo which exceeds these limits shall be transported with mechanical assist.	X 4 R P	IV-3.4 V-I-3.4 V-III-3.4
8.z Cargo in which a rupture or leakage through the containers would result in uncontrolled motion of the cargo because of propulsive forces beyond a single man's capability to control or because toxicity requires immediate abandonment and evacuation of the area shall not be hand-carried.	X 4 G R	IV-3.4 V-I-3.4 V-III-3.4
9.aa Packaging of hand-carried cargo shall be provided with multiple handholds, shall allow forward visibility by the controlling personnel, and shall be capable of surviving impact against a sharp object at 3 m/sec (10 ft/sec).	X 2 R P	IV-3.2 V-I-3.2 V-III-3.2
10.bb Provisions shall be made for rapidly securing hand-carried cargo to various structural points along the transfer path so as to prevent loss of control of the cargo in the event of an emergency.	X 2 R P	IV-3.2 V-I-3.2 V-III-3.2
11.cc The transfer of cargo with mechanical assist shall either be visually monitored by personnel who are free of other duties, or shall be provided with sensing devices which automatically stop the motion if the cargo interfaces with structure or equipment.	X 4 R P	IV-3.4 V-I-3.4 V-III-3.4
12.ff Personnel will not be located during cargo transfer in positions which can result in their entrapment if the cargo transfer mechanism fails.	X 4 R R	IV-3.4 V-I-3.4 V-III-3.4
13. Cargo beyond the limits allowed for hand transfer shall be transferred on guide rails or other mechanisms which positively constrain the angular and linear motion of the cargo except in the direction of motion.	X 1 R P	IV-3.1 V-I-3.1 V-III-3.1

(Continued on Page 3.)



HAZARD/EMERGENCY ANALYSIS  
(CONTINUED)

PAGE 3 OF 3

NO.	1.3.004
DATE	8-20-71

HAZARD/EMERGENCY

Failure of transfer mechanism and/or loss of control of cargo during transfer in pressurized or unpressurized areas.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (cont)

14dd Cargo handling mechanisms shall allow for stoppage of the motion, reversal of the motion, or release of the cargo at any point along the transfer path.

X 1 R P

IV-3.1  
V-I-3.1  
V-III-3.1

15gg Emergency procedures shall be available for the release, handling and transportation of remotely controlled cargo in the event of failure of the handling mechanism, or of damage to the packaging of the cargo.

X 4 G P

IV-3.4  
V-I-3.4  
V-III-3.4

16hh Cargo handling mechanisms shall be designed to withstand the propulsive forces that would result from a leaking or ruptured fluid cargo.

X 1 R R

IV-3.1  
V-I-3.1  
V-III-3.1

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	1.3.005
DATE	8-13-71

## HAZARD/EMERGENCY

SOURCE II-2.3 4

A radioactive environment in a sortie module or space station, resulting from exposure or escape of radioactive material during transfer and handling of radioactive materials.

## ASSUMPTIONS

1. Equipment exposure to radiation environment is not hazardous.
2. Radioactive materials will be carried in pressurized sortie modules and space station modules only, but these may be unmanned at times.
3. Normal precautions for radioactive materials are included as part of the experiment.
4. Typical radioactive sources are identified below:  
(Continued on Page 2.)

## POTENTIAL EFFECTS

1. Exposure of orbiter, sortie module, or space station personnel to excessive radiation.
2. Loss of control of radioactive material.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1. Spare shielded containers shall be available in which radioactive materials can be temporarily stored in the event of an accident.	X 2 R R	V-I-3.2 V-III-3.2
2. Means shall be provided for locating radioactive material which has been inadvertently released in a module.	X 2 R R	V-I-3.2 V-III-3.2
3. The environmental control systems of modules containing radioactive material which can result in unacceptable radioactivity levels in the event the radioactive material is released in the atmosphere, shall be capable of operating without contaminating the atmosphere of the orbiter or other interfacing spacecraft or modules.	- 1 R R	--
4. Capability shall be provided to rapidly evacuate personnel from and seal off radioactively contaminated modules until they can be returned to earth.	X 1 R R	IV-4.1 IV-4.3 V-I-3.1 V-III-3.1
5. The environmental control systems of modules containing radioactive material shall be capable of extracting and containing radioactive material inadvertently released in the atmosphere.	- 1 R R	--
6. Means shall be available for decontaminating equipment and personnel exposed to radioactive material and for storing and returning to earth radioactively contaminated clothing and other material.	X 1 R R X X X X	IV-4.1 IV-4.3 V-I-3.1 V-JII-3.1

RECOMMENDED (X) OR NOT (-)

NO. OF HRPS (1, 2, 3, 4, )

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD

RESIDUAL HAZARD

X

# HAZARD/EMERGENCY ANALYSIS (CONTINUED)

PAGE 2 OF 2

NO.	1.3.005
DATE	8-13-71

## HAZARD/EMERGENCY

A radioactive environment in a sortie module or space station, resulting from exposure or escape of radioactive material during transfer and handling of radioactive materials.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

## ASSUMPTIONS (cont)

### 4. (Continued)

<u>Source</u>	<u>Quantity</u>	<u>Discipline</u>	<u>Experiment</u>	<u>Usage</u>
Co <sup>60</sup> or Cs <sup>137</sup>	2-3 curies	Life Sciences	Radiobiology	Gamma Isotope Radiation Source.
C-14 Methionine	Unknown	Life Sciences	Role of gravity in life processes of microscopic organisms and cultured tissues.	----
Sr <sup>89</sup>	10 milli- curies	Life Sciences	Effect of the space environment on invertebrate behavior.	Radiation Source for tribolium experiments.

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.001
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE II-3.2.3

Impairment of visibility at critical moment during docking.

### ASSUMPTIONS

1. Direct visual or video visual cues are required to maneuver vehicle to contact alignment.
2. Sunlight and/or artificial light are required for docking.
3. Crew optical alignment or video monitor aids are required.
4. The orbiter is the active docking vehicle.

### POTENTIAL EFFECTS

1. Eye or vidicon damage from direct or reflected light.
2. Inadvertent vehicle contact and damage caused by loss of visual cues.

### REQUIREMENTS & GUIDELINES

	CODE	RGD REF.
1. Maneuvering procedures during docking shall preclude directing sunlight into controlling crew's eyes or into the vidicon tubes of the visual system.	X 4 R P	IV-3.4 V-III-4.1
2. The reflectance or surfaces on docking vehicles and the docking system that are visible to the controlling crew and T.V. cameras shall be below eye and vidicon damage levels.	X 1 R P	IV-3.1 V-III-3.1
3. The vidicon tubes for docking shall be designed for low sensitivity to tube image burn.	X 1 G P	IV-3.1 V-III-3.1
4. Redundant or replaceable lighting provisions shall be provided for docking.	X 1 R P	IV-3.1 V-III-3.1
5. Redundant or replaceable vidicon tubes shall be provided for docking.	X 1 R R	IV-3.1 V-III-3.1
6. Redundant or replaceable video monitors shall be provided.	X 1 R R	IV-3.1 V-III-3.1
7. Window, vidicon, and EVA visor filters shall be provided to protect eyes and camera from docking laser light damage.	X 2 R P	IV-3.2 V-III-3.2
	X X X X	

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.002
DATE	10-18-71

## HAZARD/EMERGENCY

## SOURCE

II-3.2.3

Loss of vehicle control prior to docking contact.

## ASSUMPTIONS

1. Active vehicle rotational control is a rate command, reaction jet control system with attitude hold capability.
2. Active vehicle translation control is an acceleration command, reaction jet control system.
3. Active vehicle is flying to target vehicle alignment of its docking system, docking system is being extended, vehicle translated to cause contact at docking interface.

## POTENTIAL EFFECTS

1. Inadvertent vehicle contact and damage.
2. Damage to docking system.
3. Inability to dock.

## REQUIREMENTS &amp; GUIDELINES

- |   | CODE    | RGD REF.            |
|---|---------|---------------------|
| 1A. The reaction jet control system shall provide redundancy to preclude "jet stuck off" conditions.  | X 1 R P | IV-3.1<br>V-III-3.1 |
| 2B. The rate command and rate/attitude feedback loops of the rotational control system shall provide redundancy to preclude "open loop" failures.         | X 1 R P | IV-3.1              |
| 3C. Inhibit capability shall be provided to control the "jet stuck on" condition.   | X 2 R R | IV-3.2<br>V-III-3.2 |
| 4. Automatic docking system stowage command capability shall be provided.   | - 1 G R | -                   |
| 5. The translational command circuits shall provide redundancy to preclude "open circuit" failures.   | X 1 R P | IV-3.1              |
| 6. The docking system shall be designed to operate with continuous command of the control system in the event that minimum impulse command has been lost. | X 1 R R | IV-3.1              |

X X X X

RESOLVED HAZARD  
RESIDUAL HAZARDRECOMMENDED (X) OR NOT (-)  
NO. OF NRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.003
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE FI-3.2.3:

Loss of vehicle control after initial contact during docking.

### ASSUMPTIONS

1. Capture has been accomplished.
2. Both vehicles are in attitude hold.

### POTENTIAL EFFECTS

1. Jackknifing vehicle contact and damage.
2. Jackknifing vehicles damage to capture interface release system.
3. Vehicle damage from excessive reaction jet plume impingement.

### REQUIREMENTS & GUIDELINES

- 1A. The reaction jet control system shall provide redundancy to preclude "jet stuck on" and jet stuck off" conditions.
- 2B. The rate command and rate/attitude feedback loops of the rotational control system shall provide redundancy to preclude "open loop" failure
- 3C. Inhibit capability shall be provided to control the "jet stuck on" condition.
4. Docking system rapid emergency release capability shall be provided.
5. Thermal protection shall be provided to prevent jet plume impingement damage from an out-of-control docking vehicle.
6. The docking system shall be designed to withstand normal jackknifing vehicle dynamics and will limit attitude excursions to within pre-scribed limits as determined by vehicle geometry to prevent inadvertent vehicle contact.

CODE	RGD REF.
X 1 R P	IV-3.1 V-III-3.1
X 1 R P	IV-3.1
X 2 R R	IV-3.1 V-III-3.1
X 1 R R	IV-3.1 V-III-3.1
- 1 G R	-
X 1 R R	IV-3.1 V-III-3.1

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.004
DATE	10-18-71

## HAZARD/EMERGENCY

## SOURCE

II-3.2.3;

Failure to inhibit attitude hold of one vehicle after capture during docking.

## ASSUMPTIONS

1. Capture has been accomplished.
2. Attitude hold must be done by one vehicle only during and after rigidizing to avoid attitude control system incompatibilities.

## POTENTIAL EFFECTS

1. Docking system damage by oscillating motion and loads.
2. Vehicle damaged from failed extendible docking system.
3. Vehicle damage from excessive reaction jet plume impingement.

## REQUIREMENTS &amp; GUIDELINES

- |   | CODE    | RGD REF.                                   |
|---|---------|--|
| 1. Positive, redundant indication of docking capture latch shall be provided the vehicle which is to inhibit its control system.  | X 3 P R | IV-3.3<br>V-III-3.3                        |
| 2. Either manual and/or redundant automatic attitude hold inhibit functions shall be provided to the applicable docking vehicle on indication of capture.   | X 2 R P | IV-3.2<br>V-III-3.2                        |
| 3. The docking system shall be capable of withstanding vehicle oscillation and loads generated by inadvertent attitude control system activity of either or both vehicles during draw down to rigidize the capture interface. | X 1 R R | IV-3.1<br>V-III-3.1                        |
| 4. Thermal protection shall be provided to prevent jet plume impingement damage from docking vehicles within the design angular and linear misalignments.   | X 1 R R | IV-3.1<br>IV-4.1<br>V-III-3.1<br>V-III-4.1 |
| 5. Control system inhibit switches shall be protected from inadvertent activation or deactivation.  | X 2 R P | IV-3.2<br>V-III-3.2                        |

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HAPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)-  
PREVENTIVE (P) OR REMEDIAL (R)

RE-OPENED/AVZ/12  
RESIDUAL HAZARD

TSC-88-3138

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.005
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE II-3.2.3

Loss of docking system function or control.

### ASSUMPTIONS

The docking system functions considered are from deployment of module from orbiter cargo bay to completion of rigidizing.

### POTENTIAL EFFECTS

1. Vehicle damage caused by loss of attenuation control.
2. Damage to latches and failure to dock attempting to use prematurely actuated latches.
3. Crew fatality due to explosive decompression if seal latches release after pressurization of interface.
4. Crew injury caused by failed release of latch stored energy.

### REQUIREMENTS & GUIDELINES

	CODE	RGD REF.
1. Positive indication of cargo bay door deployment and closure shall be provided.	X 3 R R	IV-3.1
2. Positive indication of docking capture latch status shall be provided to assure they are each (1) armed, (2) triggered, (3) engaged, and (4) locked.	X 3 R R	IV-3.3 V-III-3.3
3. Positive, redundant indication of docking port seal latch status shall be provided to assure they are each (1) armed, (2) triggered, (3) engaged, and (4) locked prior to opening transfer tunnel.	X 3 R R	IV-3.3 V-III-3.3
4. Capability shall be provided to recycle both capture and seal latches on the docking system from any phase of their status.	X 1 R R	IV-3.1 V-III-3.1
5. Docking latching systems recycle switches shall be protected from inadvertent activation.	X 2 R P	IV-3.2 V-III-3.2
6. Docking latch power source shielding shall be provided to protect crew from failure release of stored energy.	- 1 G P	-
7. Translation acceleration command minimum impulse capability shall be provided to permit station keeping drift to a minimum and reduce attenuation requirements.	X 1 G P X X X X	IV-3.1

RESOLVED HAZARD

RESIDUAL HAZARD X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)



## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE \_\_\_\_ OF \_\_\_\_

NO.	2.1.005
DATE	10-18-71

## HAZARD/EMERGENCY

Loss of docking system function or control.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

POTENTIAL EFFECTS (continued)

5. Entry prevented by failure to separate from core module, stow core module, or close cargo bay doors.

REQUIREMENTS & GUIDELINES (continued)

8. Bore sight alignment of video or direct visual view with the center line or the docking interface from a point not greater than 2.0 meters from the docking plane shall be provided to reduce contact energy misalignment.
9. Docking port environmental covers shall be deployed and not jettisoned.

CODE RGD REF.

X 1 G P IV-3.1

X 1 R P IV-3.1  
V-III-3.1

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	

NO.	2.1.006
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE II-3.2.3

Failure of orbiter payload module deployment mechanism prior to docking.

### ASSUMPTIONS

1. The payload module must be deployed from the orbiter cargo bay, such as manipulators or a rotatable mechanism, prior to docking the module.
2. The returned payload module is stowed into the orbiter cargo bay by the same mechanism before the orbiter can return to earth.

### POTENTIAL EFFECTS

1. Docking prevented by failure of deployment release.
2. Partially deployed module prohibits entry of orbiter.
3. Recontact with cargo bay causes module or cargo bay damage.

### REQUIREMENTS & GUIDELINES

1. Positive means for jettisoning the payload module shall be provided in the event of a failure of the payload deployment mechanism.
2. Guiderails or similar device shall be provided to prevent recontact between payload module and cargo bay in the event of deployment mechanism failure.
3. Positive means for jettisoning or collapsing payload deployment mechanism shall be provided if mechanism will at any point in the deployment destruct the closure of the cargo bay doors.

CODE RGD REF.

X 1 R R	IV-3.1
X 1 R R	IV-3.1
X 1 R R	IV-3.1

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.007
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE II-4.2.2.3

Hardware protrusions in the docking tunnel.

### ASSUMPTIONS

The docking tunnel is used for personnel transfer when the two vehicles are docked and rigidized.

### POTENTIAL EFFECTS

1. Injury to crew from bumping into protrusions.

### REQUIREMENTS & GUIDELINES

1. All hardware in the docking tunnel will be flush mounted to interior walls of the cargo/crew transfer tunnel.

#### CODE

#### RGD REF.

X 1 R P

IV-3.1  
V-III-3.1

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-) \_\_\_\_\_  
 NO. OF NRPS (1, 2, 3, 4) \_\_\_\_\_  
 REQUIREMENT (R) OR GUIDELINE (G) \_\_\_\_\_  
 PREVENTIVE (P) OR REMEDIAL (R) \_\_\_\_\_

# HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.008
DATE	10-18-71

## HAZARD/EMERGENCY

SOURCE II-3.2.31

Unsecured equipment and personnel during docking.

## ASSUMPTIONS

1. The accelerations during docking are not severe enough to cause injury to personnel or damage to equipment.
2. The velocity changes during docking are not large, but can result in out-of-control motions for untethered objects.

## POTENTIAL EFFECTS

1. Injury to crew caused by accelerated objects and crew.
2. Hardware damage.

## REQUIREMENTS & GUIDELINES

1. Stowage or tie down shall be provided for crew and critical equipment during docking.
2. Annunciator warning to all personnel shall be provided prior to manned docking maneuvers.

CODE RGD REF.

X 2 G P IV-3.2  
V-III-3.2  
X 3 R P IV-3.3  
V-III-3.3

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	

NO.	2.1.009
DATE	10-18-71

## HAZARD/EMERGENCY

SOURCE 1 II-3.2.3

Degradation of life support system during docking.

## ASSUMPTIONS

1. The docking maneuvers are under crew control.
2. The orbiter is the active docking vehicle.

## POTENTIAL EFFECTS

1. Loss of consciousness at critical moment during docking.
3. Vehicle damage caused by loss of control.

## REQUIREMENTS & GUIDELINES

1. Emergency life support provisions shall be available to the docking crew during docking operations.

CODE RGD REF.

X 1 R P IV-3.1

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HIPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.010
DATE	10-18-71

### HAZARD/EMERGENCY

SOURCE: FI-3, 2, 3.

Docking hatch opened when pressure equalization incomplete.

### ASSUMPTIONS

### POTENTIAL EFFECTS

1. Crew injury or fatality from hatch impulse and explosive decompression.
2. Hatch damage.
3. Inadvertent environment loss.

### REQUIREMENTS & GUIDELINES

	CODE	RGD REF.
1. Means shall be provided to equalize pressures on both sides of a hatch before opening it.	X 2 R P	IV-3.2 V-III-3.2
2. The pressures on each side of a hatch shall be verified before opening the hatch.	X 4 R P	IV-3.4 V-III-3.4
3. Means shall be provided to verify the integrity of a docking hatch seal before separating a docked module or vehicle.	X 3 R P	IV-3.3 V-III-3.3
4. Stops shall be provided on hatches to prevent uncontrolled opening if opened when a pressure differential exists.	X 1 R P	IV-3.1 V-III-3.1

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.1.011
DATE	10-18-71

## HAZARD/EMERGENCY

SOURCE II-3.2.3.

Electric discharge during initial docking contact.

## ASSUMPTIONS

1. Static electricity differential can exist between docking vehicles.

## POTENTIAL EFFECTS

1. Instrumentation overload damage.
2. Crew electric shock.
3. Inadvertent pyro initiation.
4. Fire/explosion from spark ignition of environment.

## REQUIREMENTS & GUIDELINES

1. Circuit breaker protection of all interface instrumentation shall be provided.
2. All docking interface equipment shall be grounded.
3. Electrical umbilicals shall be grounded until connection of the docking interface.

CODE	RGD REF.
X 2 R R	IV-3.2 V-III-3.2
X 1 R R	IV-3.1 V-III-3.1
X 1 R R	IV-3.1 V-III-3.1
X X X X	

RESOLVED HAZARD X  
RESIDUAL HAZARD

RECOMMENDED (X) OR NOT (-)  
NO. OF NRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.2.001
DATE	10-25-71

### HAZARD/EMERGENCY

SOURCE II-4.2.2.4

Loss of vehicle control in close proximity to other vehicle during docking.

### ASSUMPTIONS

The direct docking system is used, which requires the docking vehicles to be flown into close proximity.

### POTENTIAL EFFECTS

1. Inadvertent vehicle contact and damage.
2. Failure to dock.

### REQUIREMENTS & GUIDELINES

[Requirements and guidelines are the same as 2.1.002]

CODE

RGD REF.

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)



HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.2.002
DATE	10-25-71

HAZARD/EMERGENCY

SOURCE

II-3.2.4

Loss of attenuation capability during docking.

ASSUMPTIONS

1. The direct docking system is used, which employs hydraulic, short stroke attenuation.
2. An extreme operational temperature range is encountered by the docking system, leading to potential loss of the attenuation capability.

POTENTIAL EFFECTS

1. Docking system overload structural damage.
2. Failure to dock.

REQUIREMENTS & GUIDELINES

1. Thermal blanket temperature control of hydraulic components shall provide proper operating temperature.

CODE

RGD REF.

X 1 R P

IV-3.1  
V-III-3.1

X X X X

RESOLVED HAZARD	X
RESIDUAL HAZARD	

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.3.001
DATE	10-25-71

### HAZARD/EMERGENCY

### SOURCE

II-3.2.4

Loss of vehicle control prior to docking contact by extendable tunnel.

### ASSUMPTIONS

1. The extendable tunnel docking system is used.
2. Separation distance of the two vehicles prior to docking contact is such that collision by two vehicles is not likely.

### POTENTIAL EFFECTS

1. Structural damage to extendable docking system.
2. Failure to dock.

### REQUIREMENTS & GUIDELINES

[Requirements and guidelines are the same as 2.1.002]

### CODE

### RGD REF.

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-)  
 NO. OF HRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.3.002
DATE	10-25-71

### HAZARD/EMERGENCY

SOURCE II-3.2.4

Loss of vehicle control after capture by extensible tunnel docking system.

### ASSUMPTIONS

1. The extensible tunnel docking system is used.

### POTENTIAL EFFECTS

1. Structural damage to extensible system caused by buckling.
2. Damage to vehicles by contact.
3. Failure to dock.

### REQUIREMENTS & GUIDELINES

[Requirements and guidelines are the same as 2.1.003]

CODE RGD REF.

X X X X

RESOLVED HAZARD  
RESIDUAL HAZARD X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.3.003
DATE	10-25-71

### HAZARD/EMERGENCY

SOURCE II-3.2.4

Loss of pressure in the pneumatic extension and energy absorption mechanism of the docking system.

### ASSUMPTIONS

1. The extendable tunnel docking system is used.
2. A pneumatic single or double walled tunnel is used for achieving the docking system extension and for attenuation.

### POTENTIAL EFFECTS

1. Contact damage to vehicle caused by failure of energy attenuation system.
2. Failure to dock.

### REQUIREMENTS & GUIDELINES

1. Positive redundant indication of the pneumatic attenuation system status of the extendable docking system shall be provided.

CODE RGD REF.

X 3 R R IV-3.3  
V-III-3.3

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

# HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.4.001
DATE	10-25-71

## HAZARD/EMERGENCY

## SOURCE

II-3.2.4

Loss of vehicle control prior to capture by manipulator during docking.

## ASSUMPTIONS

1. The manipulator docking system is used.
2. The manipulator is deployed and fully extended prior to initial contact maneuvers.

## POTENTIAL EFFECTS

1. Structural damage to extended manipulator arms.
- .. Structural damage to vehicle from collapsed arms.
3. Failure to dock.

## REQUIREMENTS & GUIDELINES

[Requirements and guidelines are the same as 2.1.002]

## CODE

## RGD REF.

X X X X

RESOLVED HAZARD  
RESIDUAL HAZARD X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

# HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.4.002
DATE	10-25-71

## HAZARD/EMERGENCY

SOURCE II-3.2.4

Loss of vehicle control after capture by manipulator during docking.

## ASSUMPTIONS

1. The manipulator docking system is used.
2. The manipulator moves the two vehicles towards each other for docking after capture.

## POTENTIAL EFFECTS

1. Structural damage to manipulator arms caused by vehicle jackknife dynamics.
2. Structural damage to vehicle from collapsed arms.
3. Failure to dock.

## REQUIREMENTS & GUIDELINES

[Requirements and guidelines are the same as 2.1.003]

CODE RGD REF.

RESOLVED HAZARD  
RESIDUAL HAZARD X

RECOMMEND (X) OR NOT (-)  
NO. OF HAZARDS (1, 2, 3, 4)  
RECOMMEND (X) OR NOT (-)  
PREVENTIVE (X) OR REMEDIAL (N)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	2.4.003
DATE	10-25-71

## HAZARD/EMERGENCY

## SOURCE

II-3.2.4

Loss of manipulator joint motor control during docking.

## ASSUMPTIONS

1. The manipulator docking system is used.
2. The manipulator uses electrical, hydraulic or other power activated motors at each joint for controlling its motion.
3. The manipulators are installed in the orbiter, but not in the Space Station.

## POTENTIAL EFFECTS

1. Inadvertent vehicle/docking system contact damage.
2. Vehicle contact through loss of relative motion control.
3. Failure to dock.
4. Loss of personnel if the docked module is used for personnel transfer.

## REQUIREMENTS &amp; GUIDELINES

1. Control feedback loops shall be provided on each manipulator joint control which limit motion when excessive forces or torques are experienced.
2. Redundant joint motor power supply circuits shall be provided on manipulators.
3. Arm joint on manipulators shall be designed to lock on indication of joint control or motor failure. The lock shall incorporate a slip clutch capability to prevent structural failures.
4. A manipulator inhibit or "freeze" capability shall be provided.
5. Electrical or mechanical stops shall be provided to prevent the manipulator from being driven into surfaces of its own vehicle.
6. Modules which are used for personnel transfer by manipulator docking shall be provided with EVA pressure suits for all on-board personnel, and with EVA exit capability so that the personnel can escape to the orbiter or the Space Station in the event the module becomes stranded between vehicles by a manipulator failure.

## CODE

## RGD REF.

X 2 R R IV-3.2

X 1 G P IV-3.1

X 2 R R IV-3.2

- 1 G R -

X 2 G R IV-3.2

- 1 R R -

X X X X

RESOLVED HAZARD	
RESIDUAL HAZARD	X

RECOMMENDED (X) OR NOT (-) \_\_\_\_\_  
 NO. OF HRPS (1, 2, 3, 4) \_\_\_\_\_  
 REQUIREMENT (R) OR GUIDELINE (G) \_\_\_\_\_  
 PREVENTIVE (P) OR REMEDIAL (R) \_\_\_\_\_

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	2.4.003
DATE	10-25-71

## HAZARD/EMERGENCY

Loss of manipulator joint motor control during docking.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (continued)

	CODE	RGD REF.
7. Modules which are used for personnel transfer by manipulator docking shall provide emergency life support for all on-board personnel until they can be rescued by external means in the event the module becomes stranded between vehicles by a manipulator failure.	- 1 R R	-
8. Personnel will only be transferred between the orbiter and the station through a rigidly connected docking interface between the two vehicles.	X 4 R R	IV-3.4 V-III-3.4
9. Two or more manipulators shall be provided in a manipulator docking system. Each manipulator shall be capable of performing docking by itself, and shall also be capable of continuing any docking function in the event of a failure of the other manipulator at any stage of the docking.	X 1 R R	IV-3.1 V-III-3.1
10. An emergency jettisoning capability shall be provided for manipulators, independent of the normal manipulator system. This shall be capable of jettisoning the manipulator and configuring the orbiter for reentry and landing following a failure or accident which does not allow stowage of the manipulator.	X 1 R R	IV-3.1



## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	

NO.	2.4.004
DATE	10-25-71

### HAZARD/EMERGENCY

### SOURCE

II-3.2.4

Loss of manipulator computer aided control system during docking.

### ASSUMPTIONS

1. The manipulator docking system is used.
2. The control system is computer aided.
3. The manipulators are installed in the orbiter, but not in the Space Station.

### POTENTIAL EFFECTS

1. Inadvertent vehicle/docking system contact damage.
2. Vehicle contact through loss of relative motion control.
3. Failure to dock.
4. Loss of personnel if the docked module is used for personnel transfer.

### REQUIREMENTS & GUIDELINES

1. Redundant control feedback loops shall be provided each axis of computer aided control for the manipulator.
2. The manipulator computer aided control system shall fail to the "no command" mode.
3. Manual override of computer aided manipulator control shall be provided.

### CODE

### RGD REF.

X 1 R P	IV-3.1
X 1 G R	IV-3.1
X 1 R R	IV-3.1

X X X X

RECOMMENDED (X) OR NOT (-)  
 NO. OF MRPS (1, 2, 3, 4)  
 REQUIREMENT (R) OR GUIDELINE (G)  
 PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	X
RESIDUAL HAZARD	

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	
	SORTIE	
	STATION	

NO.	2.5.001
DATE	10-25-71

## HAZARD/EMERGENCY

## SOURCE

II-3.2.5

Loss of communications/command capability during docking by unmanned free flying module.

## ASSUMPTIONS

1. The free flying module docking mode is used.
2. The free flying module is unmanned.

## POTENTIAL EFFECTS

1. Vehicle damage by contact.
2. Stranded free flying module.

## REQUIREMENTS &amp; GUIDELINES

## CODE

## RGD REF.

- 1.D Space station modules which are used in the free flying docking mode shall be provided with redundant means for communication, guidance, control, power, propulsion, and other functions critical to the docking.
- 2.E The operational status of systems on Space Station modules which are used in the free flying docking mode, including redundant systems, shall be verified before the module is separated from the orbiter or station.

- 1 R P

-

- 4 R P

-

X X X X

RESOLVED HAZARD

RESIDUAL HAZARD

X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	
	SORTIE	
	STATION	X

NO.	2.5.002
DATE	10-25-71

## HAZARD/EMERGENCY

SOURCE II-3.2.5

Loss of propulsion or control capability during docking by manned free flying module.

## ASSUMPTIONS

1. The free flying module docking mode is used.
2. The free flying module is manned by crew and/or passengers, but may be controlled from on-board or from the orbiter or station.
3. The life support system capability is for a few hours only, and emergency rescue or escape can exceed this duration.

## POTENTIAL EFFECTS

1. Vehicle damage by contact.
2. Stranded free flying module.
3. Loss of on-board personnel.

## REQUIREMENTS &amp; GUIDELINES

	CODE	RGD REF.
1.A The reaction jet control system shall provide redundancy to preclude "jet stuck off" conditions.	X 1 R P V	-III-3.1
2.B The rate command and rate/attitude feedback loops of the rotational control system shall provide redundancy to preclude "open loop" failures.	X 1 R P V	-III-3.1
3.C Inhibit capability shall be provided to control the "jet stuck on" condition.	X 2 R R V	-III-3.2
4.D Space Station modules which are used in the free flying docking mode shall be provided with redundant means for communication, guidance, control, power, propulsion, and other functions critical to the docking.	- 1 R P	-
5.E The operational status of systems on Space Station modules which are used in the free flying docking mode, including redundant systems, shall be verified before the module is separated from the orbiter or station.	- 4 R P	-
6.F Emergency procedures shall be available for the orbiter to pursue and, if possible, dock to a Space Station module used in the free flying module docking mode which has lost control. These procedures shall allow personnel escape or	- 4 R R X X X X	-

RECOMMENDED (X) OR NOT (-)

NO. OF HRPS (1, 2, 3, 4)

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD

RESIDUAL HAZARD X

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

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NO.	2.5.002
DATE	10-25-71

## HAZARD/EMERGENCY

Loss of propulsion or control capability during docking by manned free flying module.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

REQUIREMENTS & GUIDELINES (continued)

## 6.F (continued)

rescue within their life support capability.

- 4 R R

-

7.G Pressure suits and back packs shall be provided for all personnel on-board Space Station modules used in the free flying module docking mode. These suits shall be suitable for emergency EVA escape to a nearby Space Station or orbiter.

- 2 R R

-

8.H An airlock capability which allows all on-board personnel to perform EVA emergency escape shall be provided on-board Space Station modules used in the free flying module docking mode. This may be provided by a separate 2-man airlock, or may be an integral capability of the whole module.

- 1 R R

-

9.I Emergency life support capability for all on-board personnel shall be provided on Space Station modules used in the free flying docking mode until emergency escape or rescue can be achieved.

- 2 R R

-

## HAZARD/EMERGENCY ANALYSIS

PROGRAM	SHUTTLE	
	SORTIE	
	STATION	

NO.	2.5.00?
DATE	10-25-71

### HAZARD/EMERGENCY

SOURCE II-3.2.5

Loss of life support capability during docking by manned free flying module.

### ASSUMPTIONS

1. The free flying module docking mode is used.
2. The free flying module is manned by crew and/or passengers, but may be controlled from on-board or from the orbiter or station.
3. The life support system capability is for a few hours only, and emergency rescue or escape can exceed this duration.

### POTENTIAL EFFECTS

1. Loss of on-board personnel.
2. Stranded free flying module.

### REQUIREMENTS & GUIDELINES

- 1.D Space Station modules which are used in the free flying docking mode shall be provided with redundant means for communication, guidance, control, power, propulsion, and other functions critical to the docking.
- 2.E The operational status of systems on Space Station modules which are used in the free flying docking mode, including redundant systems, shall be verified before the module is separated from the orbiter or station.
- 3.F Emergency procedures shall be available for the orbiter to pursue and, if possible, dock to a Space Station module used in the free flying module docking mode which has lost control. These procedures shall allow personnel escape or rescue within their life support capability.
- 4.G Pressure suits and back packs shall be provided for all personnel on-board Space Station modules used in the free flying module docking mode. These suits shall be suitable for emergency EVA escape to a nearby Space Station or orbiter.

CODE RGD REF.

- 1 R P -

- 4 R P -

- 4 R R -

- 2 R R -

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD	
RESIDUAL HAZARD	X

# HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	2.5.003
DATE	10-25-71

## HAZARD/EMERGENCY

Loss of life support capability during docking by manned free flying module.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (continued)

- 5.H An airlock capability which allows all on-board personnel to perform EVA emergency escape shall be provided on-board Space Station modules used in the free flying module docking mode. This may be provided by a separate 2-man airlock, or may be an integral capability of the whole module.
- 6.I Emergency life support capability for all on-board personnel shall be provided on Space Station modules used in the free flying docking mode until emergency escape or rescue can be achieved.

CODE

RGD REF.

- 1 R R

-

- 2 R R

-



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.001
DATE	12-17-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Fire/toxic environment.

### ASSUMPTIONS

1. The fire and/or toxic environment is severe enough to require evacuation from the immediate area, but does not result in personnel injury.
2. Means are available for extinguishing fires and getting rid of toxic environments, which can be activated remotely from other compartments.
3. The immediate sphere of influence of the fire or toxic environment is of the order of 3 m. (10 ft) diameter.

### POTENTIAL EFFECTS

1. Loss of personnel from a contaminated environment and/or heat.
2. Loss of vehicle.

### REQUIREMENTS & GUIDELINES

	CODE	RGD REF.
1. The orbiter shall be divided into two or more compartments which can be rapidly sealed off in an emergency to prevent the ingress of flames and contaminated atmosphere from the other compartment(s). Each of these compartments shall be capable of accommodating all on-board orbiter personnel until the fire and/or toxic environment can be eliminated and a habitable environment restored.	X 1 R R	IV-3.1
2A. Capability shall be provided to reduce the pressure in each compartment sufficiently, or increase it in the adjoining compartment(s) and to cut off air circulation, so that in an emergency the atmosphere in the affected compartment will not be propagated into adjoining compartments. This capability shall be controlled remotely from each compartment.	X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
3B. Automatic venting capability shall be provided in each compartment so that in the event of a fire or release of gases within the compartment the pressure will not exceed the structural limits of the structure or the capability of seals to other compartments to exclude the contaminated atmosphere.	X 2 K R	IV-3.2 V-I-3.2 V-III-3.2
	X X X X	

RECOMMENDED (X) OR NOT (-)  
NO. OF MRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	3.1.001
DATE	12-17-71

## HAZARD/EMERGENCY

Fire/toxic environment.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET I.)

REQUIREMENTS & GUIDELINES (Cont)CODERGD REF.

- 4C. Normally habitable compartments of more than 25 m<sup>3</sup> (880 ft<sup>3</sup>) in volume shall have two or more exits into areas which provide for personnel survival. These exits shall be at least 3 m. (10 ft) apart. X 1 R R IV-3.1  
V-I-3.1  
V-III-3.1
- 5D. Flammable, explosive or gas generating material shall be located, or the energy content limited, so that the energy content which can be propagated at any one location shall not result in over-pressurization of the compartment from heat and gas production. X 1 R R IV-3.1  
V-I-3.1  
V-III-3.1
- 6E. Flammable explosive or gas generating material within 3 m (10 ft) of the entrance to compartments with only one entry/egress path shall be limited so that the energy content, if released, will not result in damage or an environment which prevents shirtsleeve access through the entrance. X 1 R R IV-3.1  
V-I-3.1  
V-III-3.1





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North American Rockwell

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.002
DATE	12-17-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Explosion.

### ASSUMPTIONS

1. The explosion is severe enough to incapacitate personnel in the immediate vicinity, but not to cause catastrophic damage to the vehicle or module.
2. Fire, toxic contamination and loss of pressure may result from the explosion (see other hazard/emergency analyses).
3. The affected compartment or module may not be habitable until major repairs are made (in space or on the ground).

### POTENTIAL EFFECTS

1. Loss of personnel from immediate effects or from lack of medical treatment and loss of habitable environment.
2. Loss of vehicle.

### REQUIREMENTS & GUIDELINES

- 1F. Capability shall be provided for the emergency shirtsleeve survival of all on-board personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. A shirtsleeve accessible docking port shall be available. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all on-board personnel, including an available docking port.
- 2A. Capability shall be provided to reduce the pressure in each compartment sufficiently, or increase it in the adjoining compartment(s) and to cut off air circulation, so that in an emergency the atmosphere in the affected compartment will not be propagated into adjoining compartments. This capability shall be controlled remotely from each compartment.
- 3B. Automatic venting capability shall be provided in each compartment so that in the event of a fire or release of gases within the compartment the pressure will not exceed the structural limits of the structure or the capability of seals to other compartments to exclude the contaminated atmosphere.

CODE	RGD REF.
X 1 R R V	III-3.1
X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
X 2 R R	IV-3.2 V-I-3.2 V-III-3.2
X X X X	

RECOMMENDED (X) OR NOT (-) \_\_\_\_\_  
NO. OF MRPS (1, 2, 3, 4) \_\_\_\_\_  
REQUIREMENT (R) OR GUIDELINE (G) \_\_\_\_\_  
PREVENTIVE (P) OR REMEDIAL (R) \_\_\_\_\_

RESOLVED HAZARD  
RESIDUAL HAZARD

## HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	3.1.002
DATE	12-17-71

## HAZARD/EMERGENCY

Explosion.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

REQUIREMENTS & GUIDELINES (Cont)

	CODE	RGD REF.
4C. Normally habitable compartments of more than 25 m <sup>3</sup> (880 ft <sup>3</sup> ) in volume shall have two or more exits into areas which provide for personnel survival. These exits shall be at least 3 m. (10 ft) apart.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
5D. Flammable, explosive or gas generating material shall be located so that the energy content which can be propagated at any one location shall not result in overpressurization of the compartment from heat and gas production.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
6E. Flammable explosive or gas generating material within 3 m (10 ft) of the entrance to compartments with only one entry/egress path shall be limited so that the energy content, if released, will not result in damage or an environment which prevents shirtsleeve access through the entrance.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
7. Two or more entrances into normally habitable compartments of more than 25 m <sup>3</sup> (880 ft <sup>3</sup> ) in volume shall be shirtsleeve accessible from each of the other normally inhabited compartments. These entrances shall be at least 3 m (10 ft) apart.	X 1 R R	IV-3.1 V-I-3.1 V-III-3.1
8G. Emergency capability shall be provided on orbiter flights with a manned sortie module for the return to earth of all the passengers in the orbiter, without support from the sortie module.	X 1 R R	IV-3.1
9H. Emergency capability shall be provided on manned sortie modules for the return to earth of all the passengers in the sortie module, without life support from the orbiter.	X 1 G R	IV-4.3 V-I-3.1
10. The orbiter crew shall not enter manned sortie modules during the conduct of hazardous experiments.	X 4 R R	IV-3.4 IV-4.3 V-I-3.4 V-I-4.1



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.003
DATE	12-17-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Emergency evacuation

### ASSUMPTIONS

1. No catastrophic accident (such as a fire or explosion) has yet happened at the time evacuation is required.
2. Evacuation can be performed fairly deliberately -- i.e., in minutes rather than in seconds.
3. The evacuated compartment cannot be occupied again on that mission.
4. The suited orbiter crew can still have access to the crew compartment to return the orbiter to earth.

### POTENTIAL EFFECTS

Not determinable.

### REQUIREMENTS & GUIDELINES

- 1F. Capability shall be provided for the emergency shirtsleeve survival of all on-board personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. A shirtsleeve accessible docking port shall be available. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all on-board personnel, including an available docking port.
- 2G. Emergency capability shall be provided on orbiter flights with a manned sortie module for the return to earth of all the passengers in the orbiter, without support from the sortie module.
- 3H. Emergency capability shall be provided on manned sortie modules for the return to earth of all the passengers in the sortie module, without life support from the orbiter.

CODE	RGD REF.
X 1 R R	V-III-3.1
X 1 R R	IV-3.1
X 1 G R	IV-4.3 V-I-3.1
X X X X	

RECOMMENDED (X) OR NOT (-)  
NO. OF MRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.004
DATE	12-17-71

### HAZARD/EMERGENCY

SOURCE I1-4.1

Loss of pressure.

### ASSUMPTIONS

- Minutes of reaction time are available before physiological impairment or injury will result, and emergency evacuation to another compartment, or emergency donning of space suits which do not require pre-breathing, is possible if these are available.
- The source of leakage may not be detectable and repairable during the mission.

### POTENTIAL EFFECTS

- Loss of personnel.
- Loss of vehicle.

### REQUIREMENTS & GUIDELINES

- 1F. Capability shall be provided for the emergency shirtsleeve survival of all on-board personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. A shirtsleeve accessible docking port shall be available. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all on-board personnel, including an available docking port.
- 2G. Emergency capability shall be provided on orbiter flights with a manned sortie module for the return to earth of all the passengers in the orbiter, without support from the sortie module.
- 3H. Emergency capability shall be provided on manned sortie modules for the return to earth of all the passengers in the sortie module, without life support from the orbiter.

CODE RGD REF.

X 1 R R V-III-3.1

X 1 R R IV-3.1

X 1 G R IV-4.3  
V-I-3.1

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HOPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RECOMMENDED (X) OR NOT (-)

RECOMMENDED (X) OR NOT (-)

# HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	3.1.004
DATE	12-17-71

## HAZARD/EMERGENCY

Loss of pressure.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (Cont)

CODE      RGD REF.

- |  |  |
|--|--|
| 4. Pressure suits and attendant life support shall be provided for the orbiter crew on every flight.   | X 2 R R IV-3.2                                 |
| 5. Pressure suits and attendant life support shall be provided for all orbiter/sortie module passengers on missions where the configuration does not provide two separate pressurizable compartments capable of returning all passengers to earth. | X 2 R R IV-3.2<br>IV-4.3<br>V-I-3.2<br>V-I-4.1 |
| 6I. Orbiter equipment required for returning the orbiter to earth shall be capable of operating in a depressurized environment. The controls for this equipment shall be operable by crewmen in pressure suits.                                    | X 1 R R IV-3.1                                 |



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.005
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Failure to open internal hatch between pressureisolatable volumes.

### ASSUMPTIONS

1. Spacecraft may be operated with internal hatches open or closed, as found convenient, and irrespective of safety recommendations.

### POTENTIAL EFFECTS

1. Entrapment of personnel with insufficient life support or inability to leave vehicle.
2. Inability to reach critical supplies or equipment.

### REQUIREMENTS & GUIDELINES

1. Where only one shirtsleeve ingress/egress path is provided into a compartment or module, redundant means shall be available for opening the connecting hatch(es) from either side.

CODE RGD REF.

X 1 R R IV-3.1  
V-I-3.1  
V-III-3.1

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HIPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESIDUAL HAZARD

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.006
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Failure to open docking hatch after docking.

### ASSUMPTIONS

1. Docking interfaces for normal missions involving docking hatches exist between
  - a) Orbiter and manned sortie modules
  - b) Orbiter and space station modules
  - c) Space station modules and space station
2. The inoperative hatch may on either one of the interfacing vehicles.

### POTENTIAL EFFECTS

1. Isolation of personnel in a spacecraft with insufficient life support or inability to return to earth.
2. Inability to continue mission.

### REQUIREMENTS & GUIDELINES

1. Personnel shall not be allowed in a sortie or space station module during repositioning of the module from one docking port to another.
2. The space station shall be configured so that it always has at least two docking ports available which can accommodate a shuttle orbiter resupply or rescue mission.
3. Emergency life support capability shall be available on the space station following the non-arrival of the next planned orbiter until the following resupply or rescue orbiter flight.

CODE	RGD REF.
X 4 R R	IV-4.1 IV-4.3 V-I-3.4 V-III-3.4
X 1 R R	V-III-3.1
X 1 R R	V-III-3.1
X X X X	

RECOMMENDED (X) OR NOT (-) \_\_\_\_\_  
 NO. OF MRPS (1, 2, 3, 4) \_\_\_\_\_  
 REQUIREMENT (R) OR GUIDELINE (G) \_\_\_\_\_  
 PREVENTIVE (P) OR REMEDIAL (R) \_\_\_\_\_

RESOLVED HAZARD \_\_\_\_\_  
 RESIDUAL HAZARD \_\_\_\_\_



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 2

PROGRAM	SHUTTLE	X
	SORTIE	X
	STATION	X

NO.	3.1.007
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE FI-4.1

Failure to close docking hatch before undocking.

### ASSUMPTIONS

- Docking interfaces for normal missions involving docking hatches exist between:
  - Orbiter and manned sortie modules
  - Orbiter and space station modules
  - Space station modules and space station
- The inoperative hatch may be on either one of the interfacing vehicles.
- Space station personnel ascent to orbit and return to earth in the orbiter crew/passenger compartment, not in the space station modules.

### POTENTIAL EFFECTS

- Inability to undock.
- Inability to return orbiter to earth.

### REQUIREMENTS & GUIDELINES

- Capability shall be provided for the emergency shirtsleeve survival of all on-board personnel until the next resupply or emergency shuttle flight following the loss of access to any one module/compartment and the loss of equipment and supplies in that module/compartment. A shirtsleeve accessible docking port shall be available. If the loss of the module/compartment divides the station into two or more isolated habitable sections, then each section shall provide the survival capability for all on-board personnel, including an available docking port.
- Manned sortie modules and space station modules shall be designed so that they can be undocked, retrieved into the orbiter, cargo bay and returned to earth unpressurized.
- Capability shall be provided to depressurize docked modules before undocking.

CODE	RGD REF.
X 1 R R	V-III-3.1
X 1 G R	IV-4.1 IV-4.3 V-I-3.1 V-III-3.1
X 1 R R	V-I-3.1 V-III-3.1
X X X X	

RECOMMENDED (X) OR NOT (-)  
NO. OF NRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD



# HAZARD/EMERGENCY ANALYSIS

(CONTINUED)

PAGE 2 OF 2

NO.	3.1.007
DATE	12-21-71

## HAZARD/EMERGENCY

Failure to close docking hatch before undocking.

(LIST ADDITIONAL CONTENT IN THE ORDER OF SHEET 1.)

### REQUIREMENTS & GUIDELINES (Cont)

CODE RGD REF

- |   |                           |
|---|---------------------------|
| 4G. Emergency capability shall be provided on orbiter flights with a manned sortie module for the return to earth of all the passengers in the orbiter, without support from the sortie module.                 | X 1 R R IV-3.1            |
| 5H. Emergency capability shall be provided on manned sortie modules for the return to earth of all the passengers in the sortie module, without life support from the orbiter.                                  | X 1 G R IV-4.3<br>V-I-3.1 |
| 6I. Orbiter equipment required for returning the orbiter to earth shall be capable of operating in a depressurized environment. The controls for this equipment shall be operable by crewmen in pressure suits. | X 1 R R IV-3.1            |



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NC.	3.1.008
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Inability to use docking hatch for EVA when EVA required.

### ASSUMPTIONS

1. Contingency EVA may be required to correct a problem which interferes with the use of the docking hatch; e.g., the orbiter manipulator has jammed the docking mechanism on a docked module without sealing the interface.
2. The normal EVA egress is via a docking hatch.

### POTENTIAL EFFECTS

1. Inability to perform contingency EVA when required.

### REQUIREMENTS & GUIDELINES

- 1J. A backup EVA egress/ingress hatch which can be used for contingency EVA shall be available. Capability for depressurization and repressurization of the connecting compartment/module shall be provided.

CODE

RGD REF.

X 1 R R

IV-3.1

V-III-3.1

X X X X

RECOMMENDED (X) OR NOT (-)

NO. OF MRPS (1, 2, 3, 4)

REQUIREMENT (R) OR GUIDELINE (G)

PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD



Space Division  
North American Rockwell

## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	3.1.009
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Failure to close external airlock hatch when returning from EVA.

### ASSUMPTIONS

1. This emergency is considered only for missions in which EVA is planned as part of the normal operations.

### POTENTIAL EFFECTS

1. Inability of EVA personnel to return into spacecraft.

### REQUIREMENTS & GUIDELINES

- 1J. A backup EVA egress/ingress hatch which can be used for contingency EVA shall be available. Capability for depressurization of the connecting compartment/module shall be provided.
- 2K. On orbiter missions without attached manned sortie modules in which EVA is planned as part of the normal mission, pressure suits shall be carried for all on-board personnel.
3. Dual external hatches shall be provided on airlocks, either one of which can seal the airlock against the space vacuum.

CODE      AGD REF.

X 1 R R      IV-3.1  
                 -III-3.1

X 4 R R      IV-3.4

- 1 G R      ---

X X X X

RECOMMENDED (X) OR NOT (-)  
NO. OF HRP'S (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESIDUAL HAZARD

15



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## HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	X
	SORTIE	
	STATION	X

NO.	3.1.010
DATE	12-21-71

### HAZARD/EMERGENCY

SOURCE II-4.1

Failure to open internal airlock hatch when returning from EVA.

### ASSUMPTIONS

1. This emergency is considered only for missions in which EVA is planned as part of the normal operations.

### POTENTIAL EFFECTS

1. Inability of EVA personnel to return into spacecraft.

### REQUIREMENTS & GUIDELINES

- 1J. A backup EVA egress/ingress hatch which can be used for contingency EVA shall be available. Capability for depressurization of the connecting compartment/module shall be provided.
- 2K. On orbiter missions without attached manned sortie modules in which EVA is planned as part of the normal mission, pressure suits shall be carried for all on-board personnel.
3. Dual internal hatches shall be provided on airlocks, either one of which can provide access to the spacecraft.

CODE RGD REF.

X 1 R R IV-3.1  
V-III-3.1

X 4 R R IV-3.4

- 1 G R ---

X X X X

I I

RECOMMENDED (X) OR NOT (-)  
NO. OF HOPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)

RESOLVED HAZARD  
RESOLVED HAZARD

789-15-134



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# HAZARD/EMERGENCY ANALYSIS

Page 1 of 1

PROGRAM	SHUTTLE	
	SORTIE	
	STATION	X

NO.	3.1.011
DATE	12-21-71

## HAZARD/EMERGENCY

SOURCE: II-4.1

Failure to close IVA airlock hatch on depressurized/contaminated side or to open hatch on pressurized/habitable side when returning from IVA.

## ASSUMPTIONS

1. IVA as a planned activity is carried out on the Space Station only.
2. This emergency is not considered on the orbiter or sortie modules.
3. IVA suits can be used in an emergency in an EVA mode.
4. Planned IVA will use umbilicals rather than back-packs for life support.

## POTENTIAL EFFECTS

1. Inability for IVA personnel to return to a habitable environment.

## REQUIREMENTS & GUIDELINES

1. An emergency IVA or EVA return route shall be available for any planned IVA activity independent of the normal IVA airlock route. Depressurization and repressurization capability shall be provided for the additional compartment(s) or module(s) which must be used.
2. Emergency portable life support systems shall be available in the airlock sufficient to sustain IVA personnel in an emergency IVA or EVA return from a planned IVA activity.

CODE RGD REF.

X 1 R R V-3.1

X 2 R R V-III-1

X X X X

RESOLVED HAZARD  
RESIDUAL HAZARD

RECOMMENDED (X) OR NOT (-)  
NO. OF HRPS (1, 2, 3, 4)  
REQUIREMENT (R) OR GUIDELINE (G)  
PREVENTIVE (P) OR REMEDIAL (R)